Process Design Decisions and Project Economics
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Module - 1
Nature of Process Synthesis and Analysis
Lecture - 2
Hierarchical Approach to Process Design – I

Welcome, today we shall see the nature of process synthesis and analysis. We shall essentially see, as how a process design evolves through various steps and what factors need to be considered from going from one step of the design to the another step.

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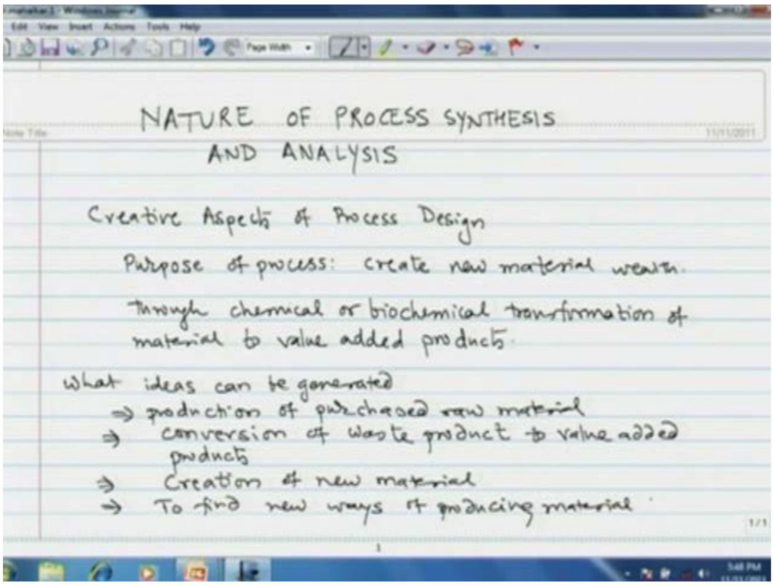

Now, let us first see the creative aspects of process design, the purpose of the process is to create new material wealth, and this material wealth is created through either chemical or biochemical transformations of the raw material or one type of material to value added products. Now, process design is about generating idea and translating into a reality.

Now, what kind of ideas that can be generated? When we are, we tried to design a process. A process design may involve production of a purchased raw material for an existing process. It may involve conversion of waste product to a value added product; again in an existing process. This will increase the revenue on by the process and its profitability. It may also bring down the level of emissions from the process. The third type of idea could be creation of completely new material; that is setting of a grass root plant. Next type of idea could be to find new ways of producing existing material. The new ways may have advantage of reduced capital cost, reduced operating cost; more environmentally safe process so on and so forth.

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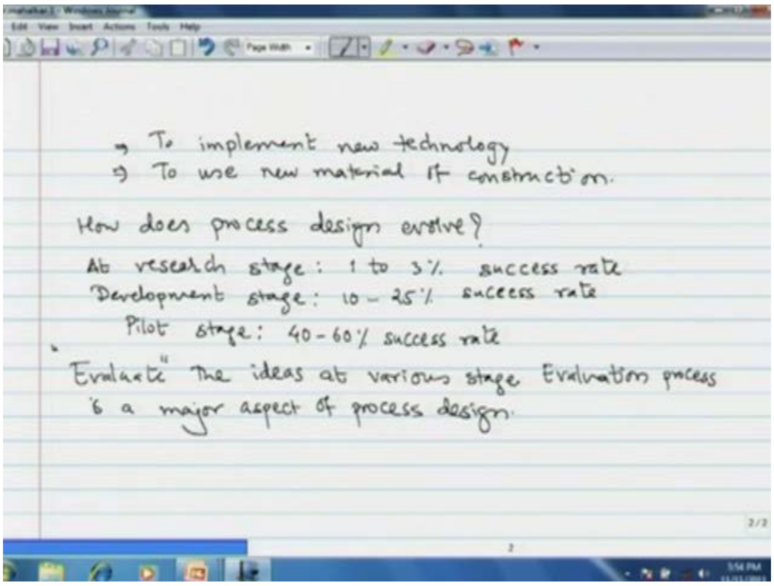

Then, the next idea could be to implement a new technology. New technology again could have a distinct advantages like reduction of capital cost, making process very safe. An example of this is the caustic soda industry. The earliest plants of caustic soda where the amalgam plant; where sodium amalgam was prepared with mercury and that amalgam was later on hydrated to give sodium hydroxide. But mercury is poisonous. So, even a small spill of mercury could give lot of environmental hazards. Then the new technology came that of a diaphragm process; where a diaphragm of a suitable material use to separate the anode and cathode compartment and that improved the process. That is basically eliminated with the use of mercury. But diaphragm process had problems of low electrical efficiency; because of the back migration of ions, ok.

Then, came the membrane technology. Now, membrane technology was a major leap in caustic soda industry. Because it not only improve the electrical efficiency; but it also gave several others advantages such as very environmental safe operation. So, that way implementation of new technology for producing the existing product can be a very creative idea for improving process design. And, then next idea could be to use new material of construction. This could be for high temperature, high pressure operation or specialty polymers so on and so forth. So, as you see that the process design is not just about designing a new process; but also improving the existing process in numerous ways. And, everywhere we want to increase the profitability of the process, it we want to make the process as environmentally safe as possible, less hazardous.

Now, how does a process design evolve? Where is this idea generated? Idea is basically generated in laboratory. Whenever we are doing experiments with new material for new processes, idea is always generated in laboratory. However, not all ideas that are generated in laboratory could be transformed into a real process. So, at research stage the idea, the chance that an idea can be translated into a commercial process is less than is about typically, let us say 1 to 3 percent. Then if the idea is sufficiently promising; then we will take it to the development stage, whether we will not only study the fundamental aspects but also the applied aspects. That is what we know as bench scale or pilot scale design of the process, and here the chance that an idea that could be translated into a real process is about 10 to 25 percent.

Next, at the pilot stage the chance that an idea or a process could be translated into a commercial process is about 40 to 60 percent. So, you can see that very few of the ideas that are generated into laboratory; ever become fruitful. However, does that mean that we should discard most of the ideas? No. It means that we have to evaluate ideas at the research stage. not only at the research stage but also at their development stage, the pilot stage. And, therefore, evaluation process is a major aspect of process design which we shall address mostly in this course.

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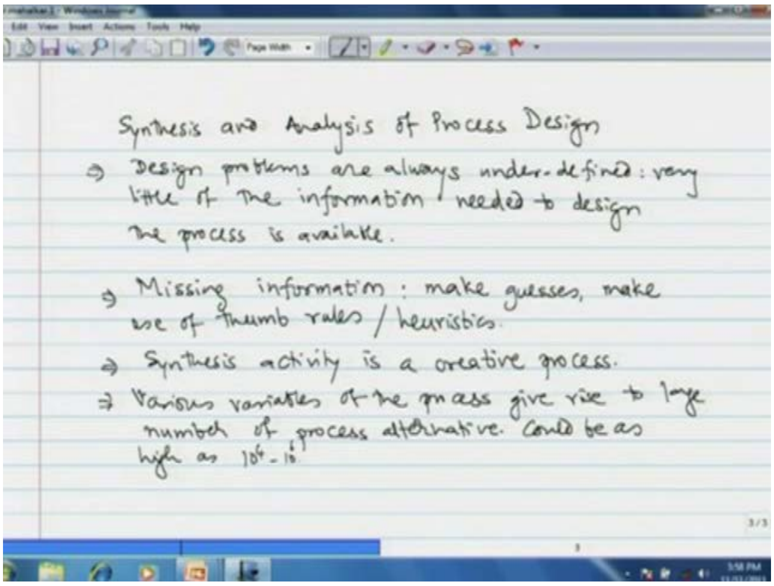

Now, how do the problems of process design differ from another problem. The major difference is in terms of information that is available. Design problems are always under-defined, which means, that very little of the information that is available to design a complete process is available at the research stage. Then how do you obtain the missing information? The missing information is either obtained by making guesses or making use of heuristics or thumb rule so on and so forth. Now, what is basically a process design? It is about selection of process equipment, the inter connection between the equipment and then translating the raw material into the final product and also the byproducts. So, synthesis activity is very much similar to draw a painting; it is an creative process.

Now, when we start designing a process, we will see that every process alternative will give various alternatives of the process design, various variables of the process. It could be in terms of temperature, pressure, catalyst, conversion; all various variables of the process give rise to large number of process alternatives. Like, typically for a petrochemical process, the number of process alternatives could be as large as 10 to power 4 to 10 to power 6. Out of these process alternatives, how do we choose the best alternative?

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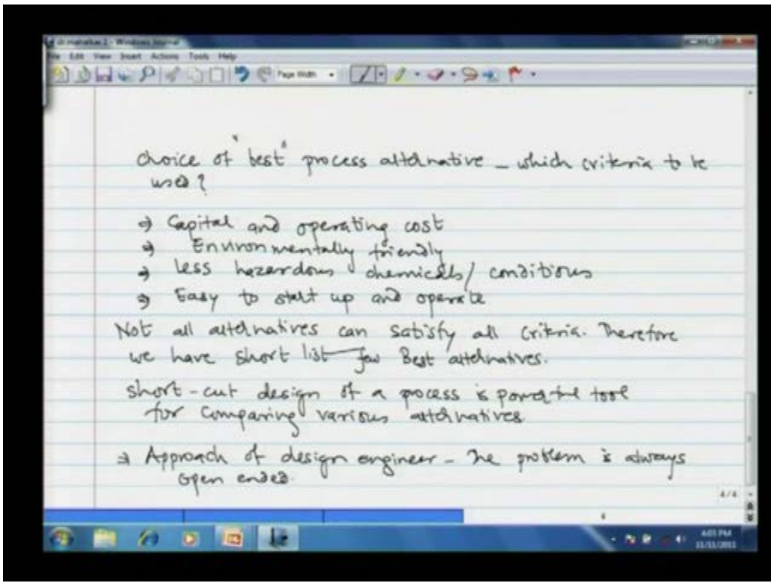

What are the yardsticks that we will use for choosing the best process alternative? The first and foremost is obviously the capital and operating cost of the process. We would like to go for a process that has the least capital and operating cost. Then it should be environmentally friendly; it should not give the rise to noxious gases, solids, liquid emission. Then it should not use any hazardous chemical or hazardous conditions.

Then, it should be easy to start up and operate so and so forth. So, these are various criteria that we will choose to; that we will use to choose the best process alternative. Now, not a single process alternative; out of the 10 to the power 4 or 10 to the power 6 processes alternatives, could satisfy all the criteria that we want. Therefore, we are very likely to end up with best few alternatives. That point we should note; not all alternatives can satisfy all criteria. Therefore, we have to shortlist the few best alternatives. Designing of such large number of process alternatives is also highly time consume, consuming activity.

Now, to compare various process alternatives, is it necessary for us to design the process to completion. Or can we design it only to a certain level; where we can estimate the operating and capital cost and then we can use other criteria? So, short-cut design of a process is a powerful tool for comparing various alternatives. Now, the approach of engineers could differ. How? As I just said that, how will you obtain the missing information to design a process? You have to either use your own experience or you have to use some thumb rules or you have search literature where anyone has reported the same or similar process and then make use of the best possible information available. But the problem is always very open ended. And, this the guess work or the heuristics that you apply, will have a major impact on the accuracy of process design.

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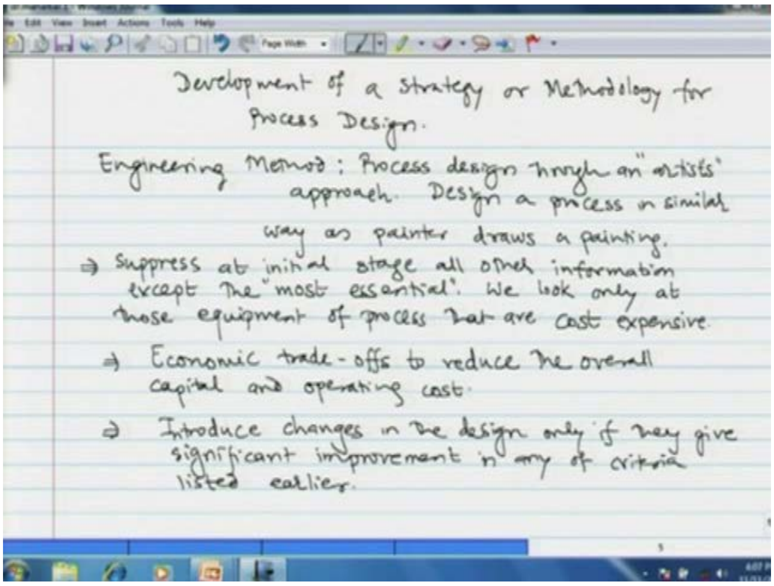

And, therefore, we would like to develop a methodology; development of a strategy or methodology for process design. And once the strategy is the engineering method. Engineering method is essentially process design though an artist approach, ok. That is you design a process very much similar, in a very much similar way as a painter draws a painting. That means, suppress at initial stage only all other information except the most essential. That means, most essential means basically in a process we look only at those equipment in the process, which are cost expensive.

Then, we will see what are the economic trade-offs to reduce the overall capital and operating cost. Introduce changes in the design only if they give significant improvement in any of the criteria that we listed earlier. So, if a designing is evolving in this way, that we add greater and greater levels of details as the process potential is promise able. That means, the addition of details essentially warrants certain return. This is how process will evolve. Then what is the ultimate outcome.

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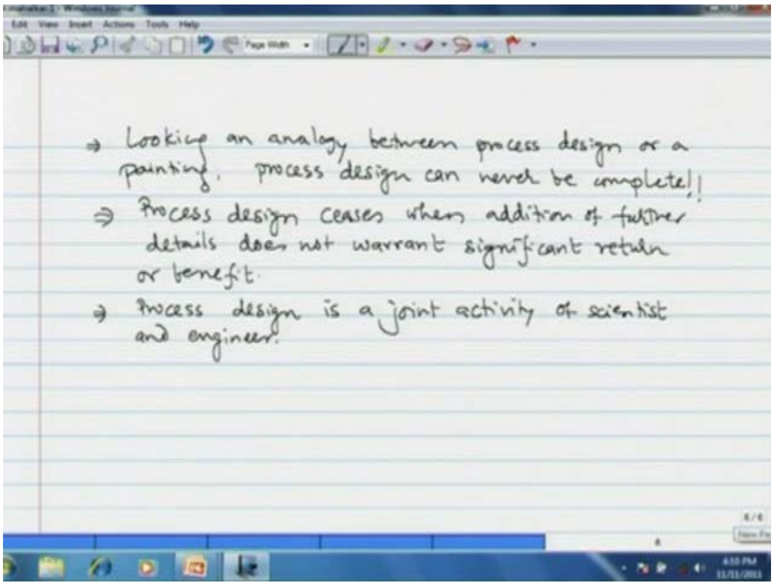

So, looking at the analogy between the process design and art or a painting; we will say that process design is never complete; process design can never be complete. Then when we stop the designing of the process; it is when the addition of additional detail or consideration of additional detail of the process does not return the significant merit. The process design ceases when addition of further details does not warrant significant return or significant benefit.

And finally I must point out that process design is a joint activity of scientist and engineer. As I said in the beginning the idea that will eventually end up or will that will eventually be translated in a process originates in a laboratory; where a scientist carries out experiments. And, then an engineer would like to transform that idea into a process. However, the scientist and engineer should never lose their hands from each other. Because scientific input would improve engineering design; and engineering whatever factors additional factors that evolve out of engineering design would be a vital input of the further scientific research. Now, having said this let us see what are the levels of engineering design?

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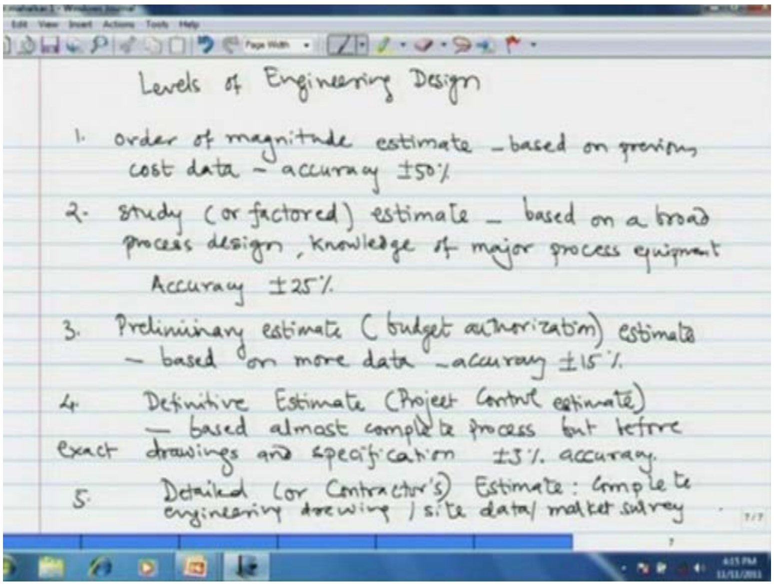

At each stage of the design we have to calculate the cost of the process. So, let us see what are the designs? The very first level of design would be the order of magnitude estimate. For example, somebody wants to start a plant of producing 10000 tons per day of methanol. Now, what is a typical cost that is involved; that is the order of magnitude estimate? Now, this is based on previous cost data and the accuracy of this estimate is about plus to minus 50 percent. The next level of estimate is what is known as the study or factored estimate. Now, this estimate is based on a broad process design; where we have knowledge of only major equipments of the process and here the accuracy is about plus minus 25 percent.

The next level of estimate is the preliminary estimate or what is also known as budget authorization estimate. Now, this is based on more data where we not only consider the major equipment; but also the utilities, energy balance other small equipment etcetera based on sufficient data. And, here the accuracy is about plus minus 15 percent; then the fourth estimate is the definitive estimate or what is also known as project cost is project control estimate. Now, this estimate is based on almost complete process, but before it is handed over to a contractor, where the exact drawings and specification are made. And, the accuracy of this estimate is about plus minus 5 percent. And, the final estimate is what is known as the detailed or contractors estimate; this is based on complete engineering drawing the side data, market surveys and here the accuracy is about 3 percent.

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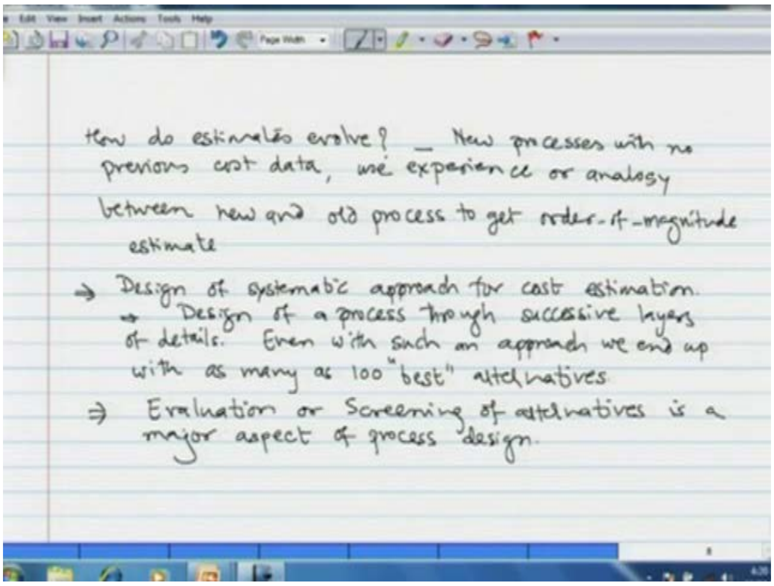

Now, how do the estimates evolve? How would I get these estimates the for a very new process where previous cost data is not available. The easy way of getting the estimate is through an experienced engineer who can make analogy; between the new process and older process and can make an excellent guess. But however such estimate is only an order of magnitude estimate; you cannot get more accurate estimates by this approach. Then how do I get an estimator, how do I design a systematic approach? That will end up in accurate estimate of a process, design of systematic approach for cost estimation.

And, now this can be achieved only by designing the process through successive layers of details; design of a process through successive layers of details. But even with this we are not going to end up with a single process alternative; that would be the best one. A s I mentioned before that evaluation process is very important; and design of a systematic approach for cost estimation is essential evaluation of the process.

And, therefore even with this approach you will end up with as many as 100 best process alternatives. But as you will see the number 100 is 2 orders of magnitude lesser then the process alternative that we had earlier that is 10 to power 4 or 10 to power 6. So, evaluation is a essential or a major activity that is which is also known as cleaning of alternatives, evaluation or screening of alternatives is a major aspect of process design. And, this is the major component or major aim of this course.

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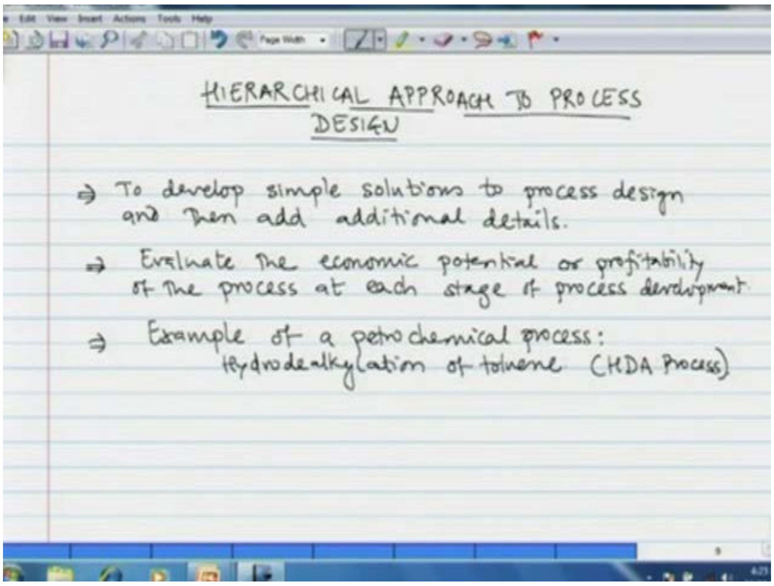

Now, we will see the hierarchical approach to process design. How do we develop design step by step or hierarchy? And, in each step we add greater and greater amount of details, greater and greater amount of information, so the hearer so the idea is to develop simple solutions for process design; and then add additional layer of details. At each stage we have to evaluate the economic potential of the process. And, only then we have to if the potential is positive then only we go to the next stage.

As I mentioned earlier there are several criteria for evaluating process; not just the profitability. However, as I said it is about screening of alternatives and we use now the only criteria of the economic potential. Now, to demonstrate the hierarchical approach of the process design; we take example of a petrochemical process which is the hydro de-alkylation of toluene, which is also known as HDA process.

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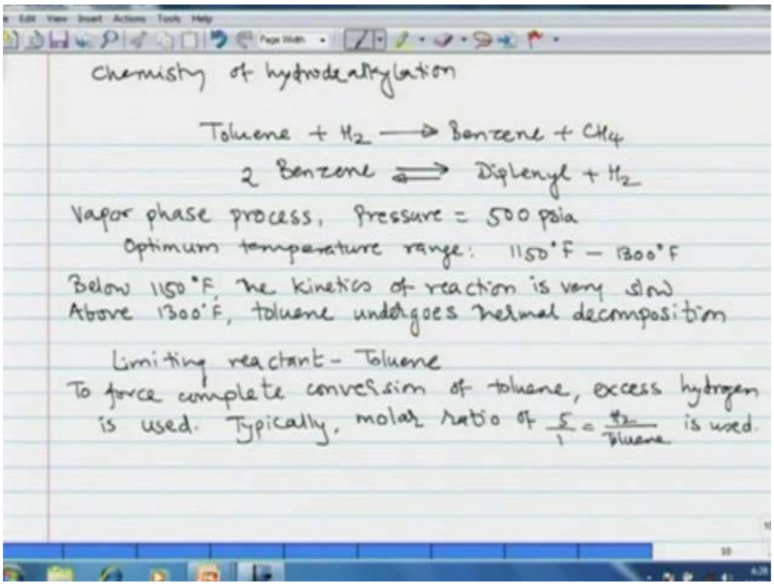

What is the hydro de-alkylation process? As I said the idea is generated in laboratory by chemist. So, let us first see the chemistry of hydro de-alkylation. In the hydro de-alkylation process toluene reacts with hydrogen to give benzene and methane. And, there is also a side reaction that 2 molecules of benzene combine reversibly to give diphenyl and hydrogen. So, this is a basic chemistry. This process is a vapor phase process; the pressure of the process is about 500 psi pound per square inch absolute and the optimum temperature range is 1150 degree Fahrenheit to 1300 degrees Fahrenheit.

Now, how is this optimum temperature range determined; that below 1150 degrees Fahrenheit the kinetics of the reaction is very slow. And, above 1300 degrees Fahrenheit toluene undergoes thermal decomposition without getting converted into benzene. Now, the limiting reactant in the process is toluene. And, therefore to force complete conversion of toluene to benzene and excess of hydrogen is used. So, typically the molar ratio of 5 is to 1 is used; excess hydrogen fed to the process also has several other roles to play that will be evident later. Now, based on this information which comes from laboratory; how do we now start designing the process? Now, let us say let us see how we can develop a very simple flow sheet for such a process?

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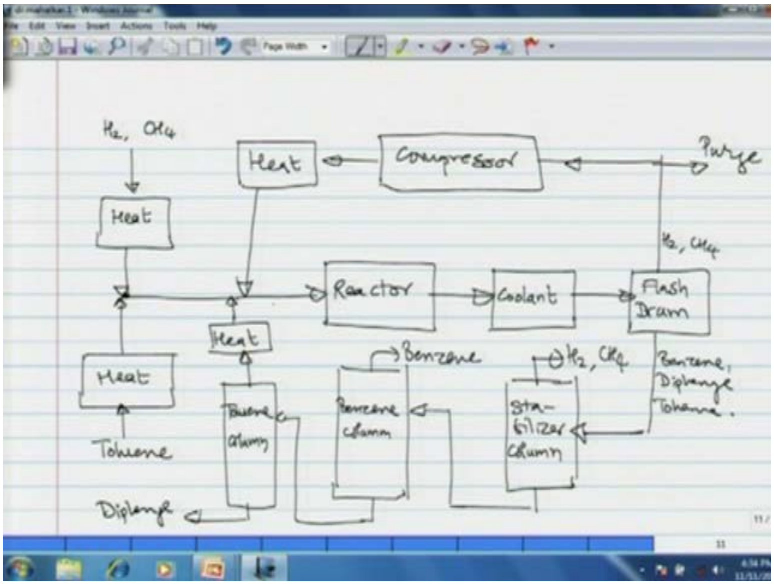

Now, both of the reactants have to be heated. So, we have one reactant in gaseous phase; hydrogen with some impurity of methane in it. Because hydrogen is generated through steam reforming of methane; this is heated. And, then it is mixed with toluene; now toluene is liquid at NTP conditions. So, it not only needs to be heated but also evaporated and then mixed here and then fed to the reactor. Now, the reactor affluent or the steams that comes out of the reactor will contain the main product benzene, the byproduct diphenyl, unconverted hydrogen, methane which is an inert impurity and also unconverted toluene.

Now, this mixture is at a temperature between 1150 to 1300 degrees Fahrenheit; so it contains lot of energy. Now, this mixture has to be first cooled and then it has to be expanded in a flash drum; where the pressure is reduced. Now, in the flash drum benzene, toluene and diphenyl which are basically heavy hydrocarbons; those will condense and hydrogen and methane will still be gases. So, 2 streams emerge out of flash drum; one is the gas stream which contains mainly hydrogen and methane, and then a liquid stream that contains benzene, diphenyl and toluene. Now, of course hydrogen and methane will have some vapor in it of both benzene and toluene. Similarly, in the liquid stream that is emerging benzene, toluene and diphenyl there will be hydrogen and methane dissolved.

Now, how do we separate these components; how do we withdraw the main product? Let us see the liquid stream first; the liquid stream is first fed to a stabilizer column where it is heated and the dissolved gases are taken off. Next this stream is fed to a second column in which the main product of the process that is benzene is distilled off; we can call this as benzene column. And, the bottoms of the benzene column which is essentially toluene and diphenyl are fed to a second column; we call this as toluene column in which the byproduct diphenyl is taken out. And, then the unreacted toluene is remixed with the fresh fed entering into the reactor after heating. So, that essentially we have withdrawal of the main product and recycle of unreacted toluene.

Now, what is the fed of the gas stream that is coming out from flash drum? Now, gas stream contains unreacted hydrogen and methane. Now, methane is entering the process as an impurity through the feed as well as it is generated into the process. Now, if this stream is recycled as it is then methane will built up in the process; and that will hamper the process.

Therefore, we use a purge stream; purge is essentially throwing off some part of the unreacted gas. The remaining gas is then compressed to restore pressure to find it psi; then it is also heated, and then mixed with the fresh stream that is entering the reactor. So, this is the basic flow sheet that we can draw from information that has emerged from a chemist. Now, in the next lecture we shall see how we can simplify this flow sheet; decompose this flow sheet into the most simplest form? And then we successively add the layers of detail and then eventually end up with a complete process design.