Lec :3 Introduction to Chemical Plant Design.

—Music Playing——Music applause— Welcome to the MOOCs course, Organic Chemical Technology. The title of today's lecture is Introduction to Chemical Plant Design. In this lecture, we will be discussing a few important aspects which are important from the chemical plant design point of view. We are not going into the details of each and every point that is essential from the design point of view. Actually, if you wanted to design an entire chemical plant, what you need to have? You need to have entire chemical engineering knowledge, you know professional thorough knowledge of chemical engineering is required. All that is not part of the course.

However, this course is primarily on chemical technology that is production of chemicals, especially organic chemical technology that is production of organic chemicals in industrial scale at the plants. At the plants, how organic chemicals are being produced that is what we are going to discuss. So, that is from the plant point of view, it is necessary to have a few information about the design aspects of the plant as well, okay? So, that is what we are going to discuss in today's lecture.

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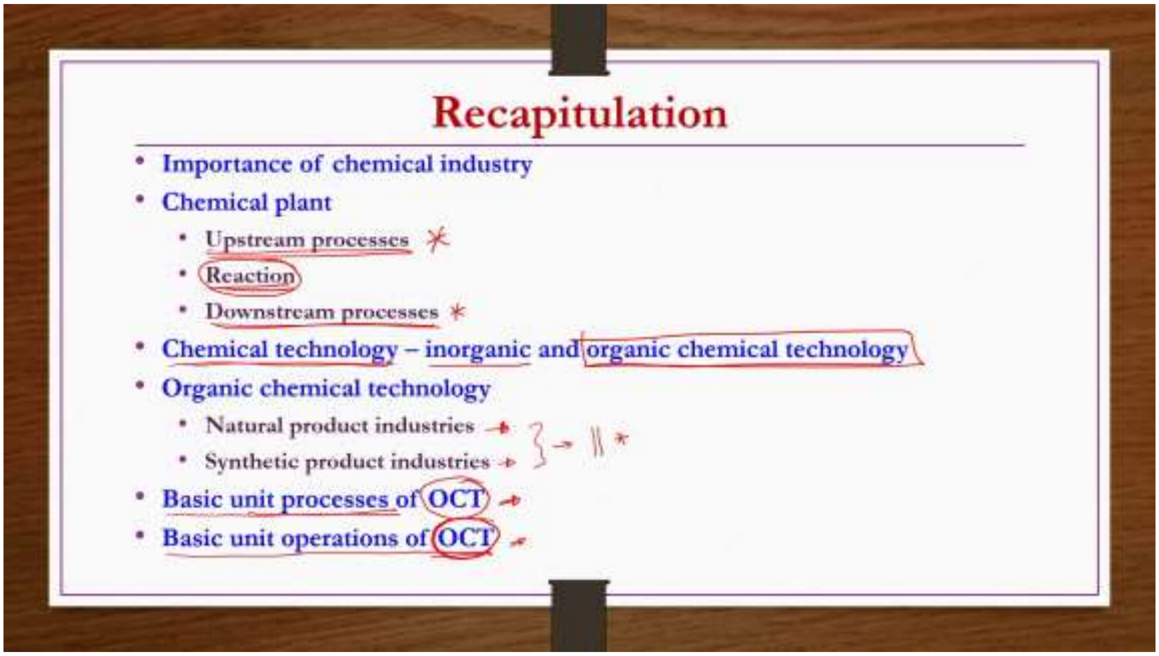

However, before going into the today's lecture details, what we will be doing? We will be having a kind of a recapitulation of what we have studied in the previous couple of lectures.

Importance of chemical industry. We started discussing from the chemical industry importance point of view, how it is going to affect or you know beneficial to the gross domestic product of a nation, especially for India it is approximately 7%. 7% of GDP is coming from the chemical industries contribution, right? So, likewise, you know, we have seen other aspects like you know overall industrial gross output if you see 45% or more is coming from the chemical industries. If you club the overall industrial output, so then whatever the gross industrial output is there, so that means you know covering all industries not only chemical industries, right? Output of all industries apart from chemical industry also. If you take together and then you see the contribution of chemical industry in that gross industrial output 45% or more is coming from the chemical industries that indicates that you know importance of the chemical industry for the growth of the nation, right? So, how it is possible? It is possible from the market.

We have seen that the chemical industrial products are the products from the chemical industries whether organic or inorganic products, whatever, polymeric or petroleum products, whatever it may be, you know, they are having different applications not only household purpose, societal purpose, industrial purpose, even defense purpose also, those products are having a market. That is the reason they are they could able to contribute a lot to the GDP of the nation, okay? Then we discussed about chemical plant. Chemical plant actually we grouped into 3 categories, rather categories like what are the things that are happening before the reaction and what are the things that are happening after the reaction and then reaction part. That is how if you see chemical plant may be grouped as upstream processes, reaction steps and then downstream processes. Upstream processes where several types of unit operations are utilized to make the raw material is suitable to undergo the reaction or the preprocessing of raw material so that it becomes suitable to undergo reaction whatever the steps are there.

So, those steps we call upstream processes and then all of them are unit operations only, physical or chemical changes only occurring. Then once you have the process to raw material, then reactions, unit processes undergo and then whenever there is a reaction apart from the product, there would be byproducts, unreacted reactants and then other impurities may also possible, right? So, then from that point of view, you see that product purification is required or separation of product or purification of product is required. So, all those things, those steps, all those operations we call them downstream operations, right? These downstream operations again unit operations where physical or chemical changes only occurring, unit processes or reactions are occurring only in the reactor stage, okay? Now, what is chemical technology? Chemical technology basically it takes into account variety of principles of chemical engineering at the industrial scale to produce different types of chemicals, whether they may be organic chemicals or they may be inorganic chemicals. So, based on the nature of the chemical produced, the chemical technology can be inorganic technology or organic chemical technology that is what we have seen. So now, the course is on the organic technology.

So, then what we have seen, we started discussing about different types of organic chemical technology or products of organic chemical industries. Then we realized those organic products may be grouped as natural product industries and synthetic product industries. So, what are the industries falling under natural product industries category, those things we have seen. Similarly, what are the products that are falling under synthetic product industries, those things we have seen. Also, there are a few products which may be produced naturally or which may be produced synthetically in a plant.

So, such kind of things also we have seen, okay? Then we have seen some basic unit processes of organic chemical technology or organic chemistry, huge number of reactions are there. We cannot go each and every reaction. Even in organic chemistry courses also we are doing only a few courses or maybe category-wise we take different reactions and discuss. So, here also we have taken a few unit processes of organic chemical technology and discussed them, right? Likewise, we also discussed basic unit operations of organic chemical technology. These unit operations are not necessarily of organic chemical technology only, they are also useful in other inorganic chemical technology as well, okay? Now, before going to the main contents of today's lecture, what we will do? We will have to see a few more common unit operations of organic chemical technology.

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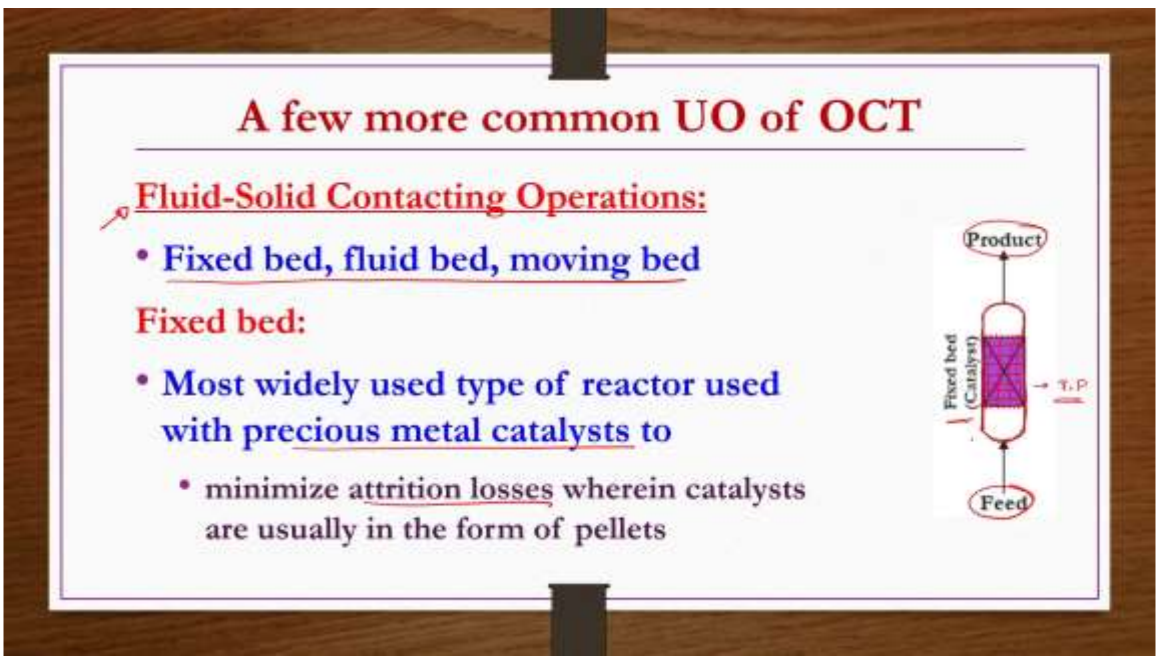

These unit operations are important for inorganic chemical technology and other chemical industries as well like polymer industries, etc. So, they are very important, so we have a look here. Fluid solid contacting operations, we are discussing a few. Fixed bed, fluid bed, moving bed. Actually, these are not only 3 types are possible.

We are discussing only a few. Fixed bed, most widely used type of reactor, it is used with precious metal catalyst to minimize attrition losses wherein catalysts are usually in the form of pellets. What happens actually some of the catalysts are very precious. In the process of the reaction if the more attrition is there, so then the physical structure may break down, pellets may be broken down into the small small fractures, etc. So, then that is not going to be useful, right? Pictorially if you see, usually packed beds or fixed beds, fixed beds are also known as the packed beds.

They are nothing but packing within a tubular column. You have a tubular column like this. Some portion of this tubular column is packed, is packed using perforated plates both bottom and then top like this, right? So, within this packing region whatever the catalyst are there, you fill them here. If it is reaction taking place, so then the catalyst are there. Otherwise non-catalytic packing materials are also there because sometimes you also need to do heat transfer.

For that purpose, also these fixed beds, etc. also used, right? So, if the reaction are there, then only this catalyst packing is there. Otherwise non-catalytic packing like sand or raschig rings are used or broken glasses, etc. are used, right? Now let us say from the reaction point of view if you see this catalytic bed is heated at certain temperature pressure, then feed material whatever gases or liquid material that is there that is allowed to pass through this bed which is already at the conditions of temperature pressure which are required for the reaction to occur. So, when this feed comes here, it passes through the perforated plate and then interstitial spaces of the catalyst, then reaction takes place because they are interacting with the catalyst, right? And then products are coming out from the top like this because the top also there is a perforated plate, okay? So, this is and then let us say if the heat transfer is to occur, the same process like you know, let us say if you are recovering heat from the bed, so then cold fluid is going into this one or if you wanted to cool down the fluid, so then bed would be at the lower temperature, then hot fluid is allowed to pass through, okay?

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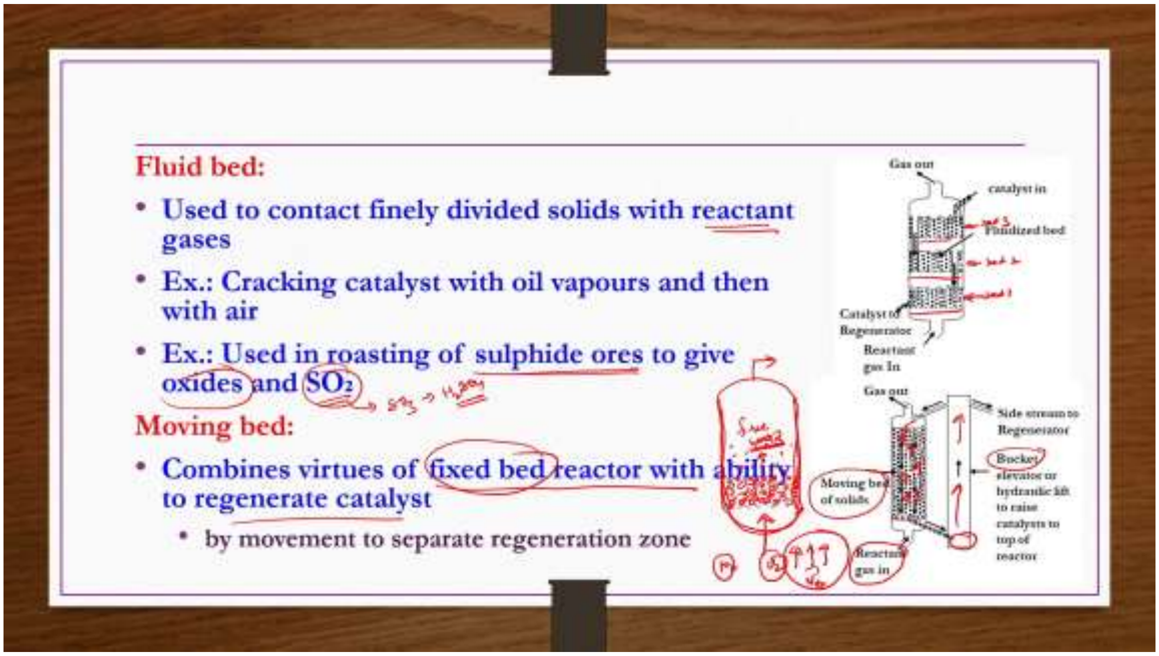

Next one is the fluid bed or fluidized bed. Different models are there here. These are used to contact finely divided solids with reactant gas. Here again it is discussed with respect to the reaction only, but in general non-reacting fluidized beds also useful in the chemical plants. Example here, cracking catalyst with oil vapors and then with air is one example for the reactive fluidized beds. Another one is used in roasting of sulfide ores to give oxide and SO_2.

Sulfide ores usually you know, they will be oxidized or roasted in a fluidized bed reactors, right? So, it is done for two purpose, to get the oxides, different oxides as well as the sulfur dioxides, right? The sulfur dioxide whatever is there that would be further oxidized to sulfur trioxide and then the sulfur trioxide react with water to get sulfuric acid and then oleum, etc., all those things you can produce. So that is the point of this roasting of sulfide ores, right? So, this is done in the fluidized bed in general, okay? There are many designs of fluidized beds, but simplest one is that is as shown here. So, let us say you have a column, cylindrical column as in the packed bed, okay? There is a perforated plate at the bottom and now whatever the catalyst particle or the medium solid medium, you know broken glasses, etc., or raschig rings, etc., whatever are there, the sand, etc., you know, they are poured on this perforated plate and now here the top is not closed. In the case of packed bed, the top of the bed is also closed so that the bed is fixed. Now it is not like that. So now the fluid medium whatever is there, let us say here, you know, oxygen is going.

Now let us say sulfide ores are there here and then your hot oxygen you are sending from here, for example. So that will pass through the perforated plates and then interstitial spaces between the particle and then goes out. If the velocity of the oxygen gradually increases, let us say, here oxygen I am calling as a fluidizing medium, it can be nitrogen also, any other reactant gases also, anything. Then what happens? The particles drag whatever is there that would be, you know, overtaken and then this particle started fluidized, lifted like this and then they will behave like a fluid particles. So that's the reason such beds are also known as the fluidized beds, rather fluid beds, they are also known as the fluidized beds because the packing material whatever are there under certain flow condition, they are under fluidized conditions.

Under certain velocities of the fluidizing medium, whatever the nitrogen, oxygen or reactant, whatever is the fluidizing medium, the packing material are under the fluidized condition. That is the reason these are known as the fluidized beds. So, now it is at the top not close, there is a freeboard, this area is all known as the freeboard where that is nothing but the free space where the particles may be lifted over while they are in fluidized conditions. Then from top the gases are collected like this. Other representation is here, such kind of fluidized regions.

Let us say now this is one bed 1, let us say this is bed 2 and then this is bed 3. Now here you can see all 3 beds, bottom there is a perforated plate, but top it is not and then between 2 perforated plates there is a free space so that the particles whatever being fluidized they can be fluidized. There should be free space for the fluidization of the particles. So, such different kind of configuration designs are possible. Basic concept is that the fluidization of the particles, whether the catalyst particles or the whatever other packing materials you have taken.

Next one is the moving bed. It combines virtues of fixed bed reactor with ability to regenerate catalyst by moment to separate regeneration zone. So, let us say here. Now here you have a bed, at the bottom there is a perforated plate and then you are providing the catalyst particle from the top and then from the bottom reactant gas is coming in. So, if the gas velocity is when it becomes higher the particles would be under fluidized conditions like this.

So, solids are moving. Some solids which are not able to fluidize they will be escaping from the bottom and collected at the bottom and then using bucket elevators they will be lifted to the top from where the catalyst particles are being sent into the column. So, this elevation and then refilling the particle from the top again it is taking place. So, it is known as the moving bed because it combines the virtues of fixed bed reactor with ability to regenerate catalyst as well.

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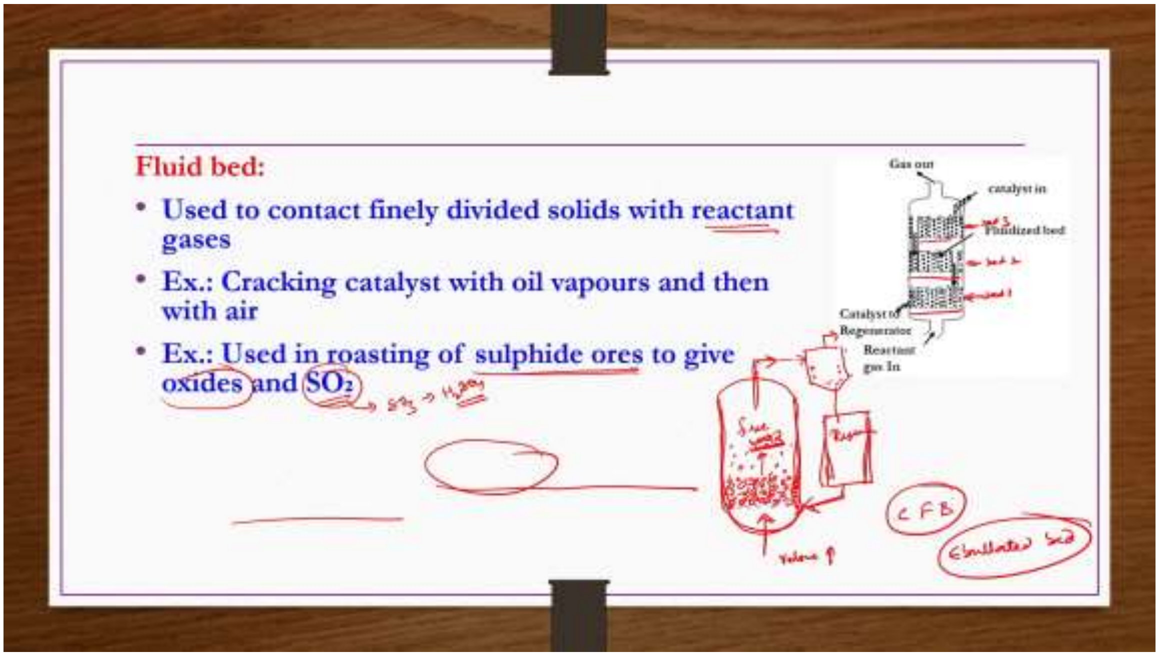

So, there is another way of, there is another method that circulating fluidized bed reactor. Let us say what happens in this fluidized bed. If the velocity is very high then it is possible that particles may be going out of the reactor. So those particles in general collected by passing through the outgoing gas through a cyclone separator. From the cyclone separator you can get the clear gas. Whatever the particles are there, they will be settling at the bottom of the cyclone separator. They will be collected and then passed through a regenerator and these particles after or these catalyst particles being regenerated here they will be sent back to the bottom of the fluidizing section again.

So, this is known as the circulating fluidized bed reactor also. Nowadays the concept of ebullated bed reactors also coming in mostly being used in industrial level. So, the concept is same, but you know how are you incorporating is different.

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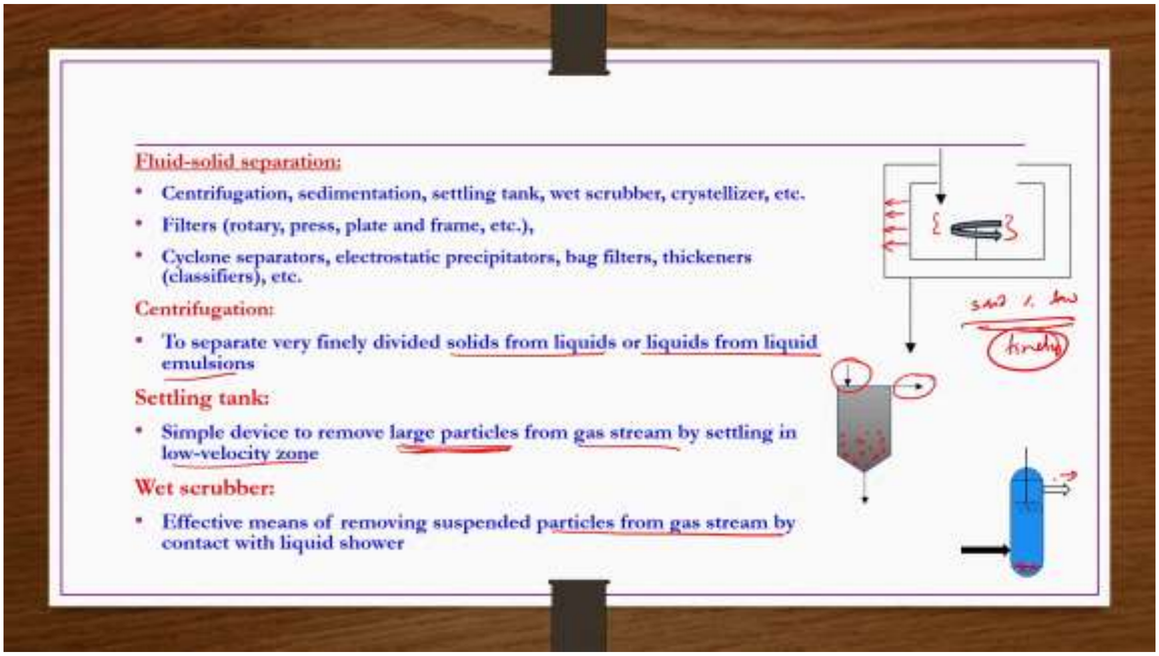

Next are solid fluid separations. There are several equipment like centrifugation, sedimentation, settling tank, wet scrubber, crystallizer, etc. Filters also there like rotary filters, filter press, plate and frame filters, etc. Cyclone separators are there, electrostatic precipitators are there, bag filters are there, thickness or classifiers are there, okay? Centrifugation what happens? They are used to separate very finely divided solid from liquids or liquid from liquid emulsions, okay? How it is? Let us say you have a ball, centrifugation is nothing but at a rotating ball. That way you can visualize. You have a ball, in that one you take whatever the solid suspension is there and then rotate it. Heavier phase would be thrown towards the wall of the ball because of the centrifugal actions.

Lighter phase would be collected towards the center of the ball and then separation of the phases takes place. Same is true for the liquid emulsions also, okay? Design principles, etc. that are not part of the course, so we are not going to see. Settling tank, they are simple settling tank. Simple in the sense, if you wanted to remove large particles, large volumes of the particle from the gas stream by settling in low velocity zone, then these settling tanks are used.

Whereas the centrifugation usually used solid percent is low. If the solid percentage is low in the liquids, then usually centrifugation is used low as well as the finely divided particles, then centrifugation is better. If you have large quantities and then bigger particles which can easily settle, why finely? If the particle is very fine, it cannot settle easily under gravity. So, then centrifugation force will accelerate separation of the such finely particles, but the particles are very large, so then they can settle easily. So, then we can use the settling tanks which are nothing but simple container.

You pass the particle laden gases through this container at low velocity, so then particles would be settled because of their large quantity as well as the bigger size, etc., whereas the clear gases are collected from the top, okay? Wet scrubber, effective means of removing suspended particles from gas stream by contact with liquid shower which is similar like settling tank. You have a column. Now what you do? Whatever the suspended particles gas stream is there or particle laden gas stream whatever is there that you allow to pass through the bottom of the container and then from the top you spray the water. So, this particle will become wetted and then settled at the bottom, whereas the wet clear gas will be collected from the top, okay?

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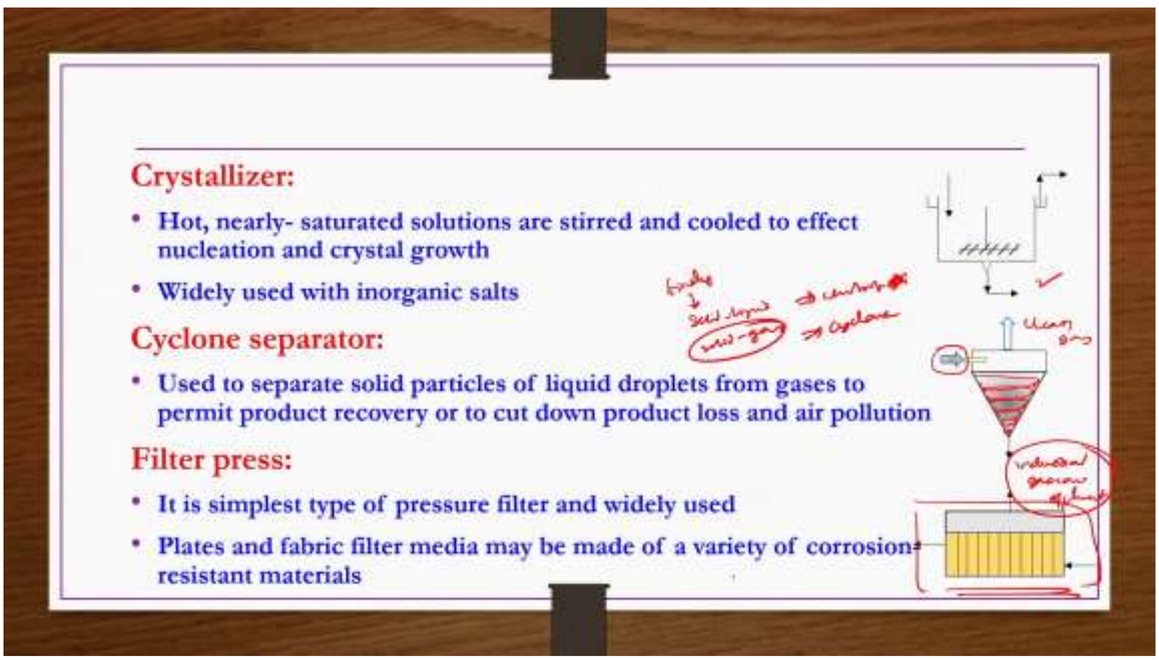

Crystallizer, their hot nearly saturated solutions are stayed and cooled to affect nucleation and crystal growth. Widely used in inorganic salts purification in general. Pictorially they are shown here. Then cyclone separators in the particle laden gases, particles are very, very fine that they cannot be settled down. So, if it is a gas phase, then you cannot use the centrifugation. If it is a solid liquid and then solids are finely divided, then you can use the centrifugation to remove.

But you have a solid gas, then you cannot use the centrifugation, right? Centrifugation is not possible here. So, then you have to do the cyclone separation. So here what you have? Pictorially you have, this is the cyclone separator. Whatever the gases which are having final particles, very fine particles, they are passed through a cyclone separator. So, then this gas hits the walls of the cyclone separator with high velocity.

So, when they hit the wall of the cyclone separators, whatever the particles that are there, they will lose their kinetic energy and then they will settle along the walls of the cyclone separator and then collected from the bottom, whereas the clean clear gas is collected from the top. Most of the industrial gaseous effluents are there. If very fine solids or fine droplets are also there, then those things are usually separated by the cyclone separators. Filter press, it is simplest type of pressure filter and widely used. Plates and fabric filter medium may be made up of variety of corrosion resistant materials in general.

Pictorially it is shown here. Many more details of filtration processes you study in mechanical unit operations course.

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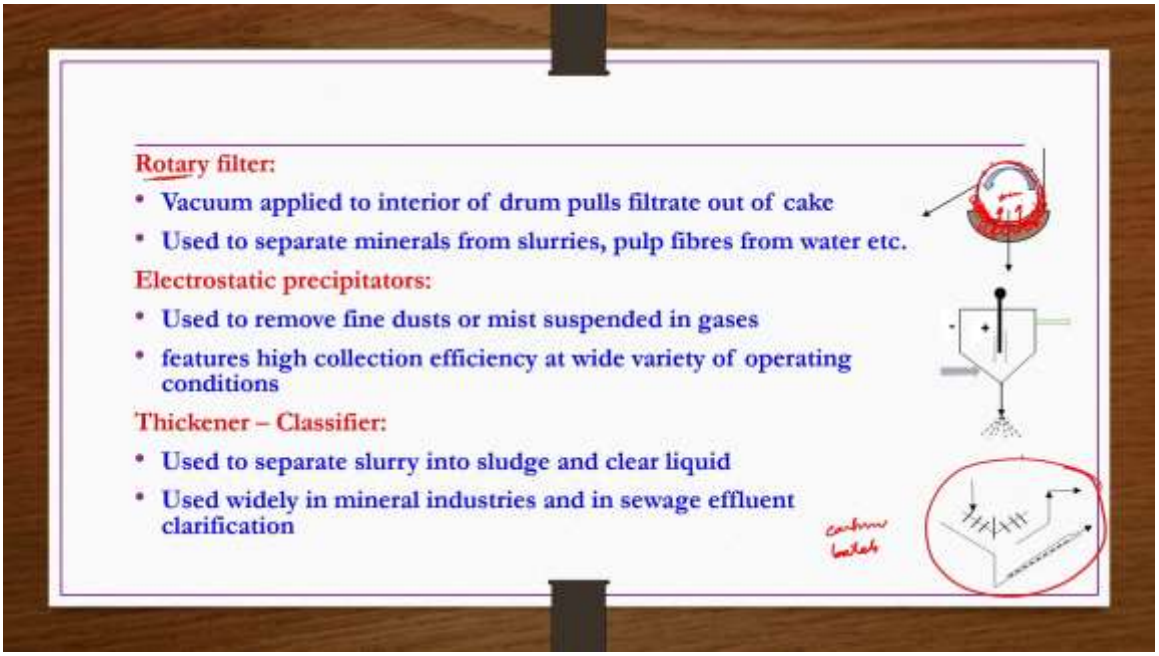

Then rotary filter, so rotary by the term there is some rotation is going on. So, vacuum applied to interior of a drum pulls filtrate out of the cake, used to separate minerals from slurries, pulp fibers from water, etc. Pictorially let us say you have a slurry here in this container and there is a drum here.

This is rotating actually. This drum is perforated drum, as well as it is covered with a cloth. Now it is rotating and then while rotating vacuum is applied in the inside of the drum. So, whatever the filtrate is there that is being sucked inside the drum and then solids are being attached to the outside of the filter cloth, okay? So, after the process, you can collect the solids from the filter cloth and then filtrate is continuously collected from the center of the or the interior of the drum, okay? Electrostatic precipitators, here the separation is based on the electrical nature of the charge of the particle that is present in this stream. It is used to remove fine dust or mis suspended in gases, features high collection efficiency at wide variety of operating conditions. The pictorial representation of electrostatic precipitator is shown here.

Then thickener classifiers used to separate slurry into sludge and clear liquid, used widely in mineral industries and in sewage sludge clarifications. These are there in continuous mode as well as the batch mode. Whatever, we have shown here it is a continuous thickener.

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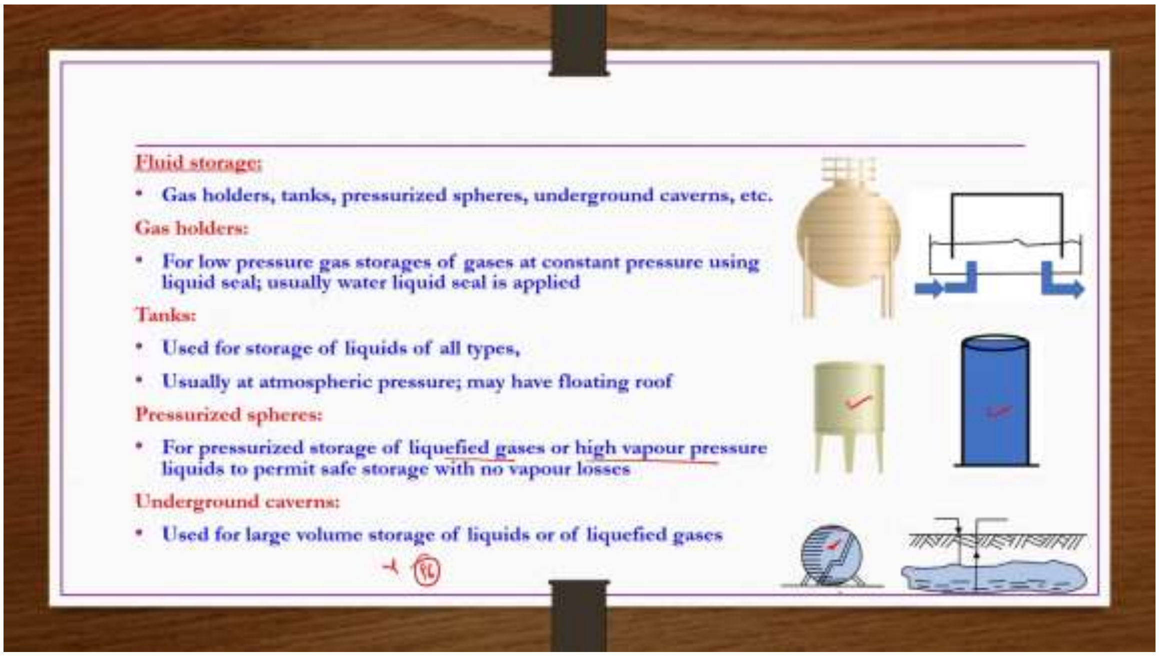

Fluid storage, gas holders, tanks, pressurized spheres, underground cabins, etc. are there.

Gas holders for low pressure gas storages of gases at constant pressure using liquid seal, usually water liquid seal is applied. So, they look like something like this or you have containers like this also, okay? Then tanks used for storage of liquids of all types, usually at atmospheric pressure, may have floating roof as well. These are very simple common type thing we often see. Then pressurized spheres used for storage of liquefied gases or high vapor pressure liquids to permit safe storage with no vapor losses.

So pictorial it is shown here. And then underground cabins also important, they are used for large volume storage of liquids or of liquefied gases, something like this. These are also used for phosphorus because this phosphorus, yellow phosphorus, etc. when they come into contact with the air immediately they catch fire. So, what we do in general after their production, these are stored underground cabins.

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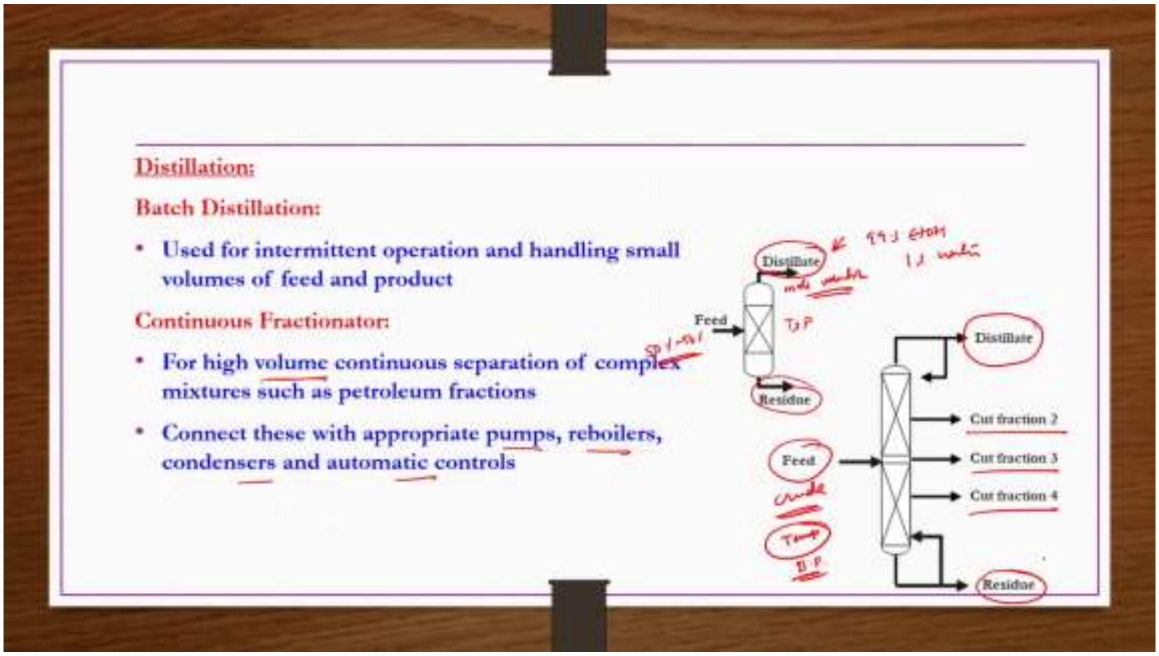

So, distillation is based on the relative volatility of the compounds that are present in a mixture.

Let us say ethanol plus water mixture is there. Out of these two, ethanol is more volatile and then water is less volatile. Based on this mixture composition, you have to select the temperature at which more ethanol is easily evaporating because it is more volatile and collected as a top product. Temperature selection depends on the boiling point of both component 1 and 2 here, here ethanol and water 2, right? So multi component distillations also similar like that only, okay? So, this distillation may be possible in batch distillation as well as the continuous distillation. Batch distillation used for intermittent operation and handling small volumes of feed and product. Let us say feed is passed through a distillation column and then temperature, pressure conditions are maintained such a way that more volatile component gets easily purified as a top distillates whereas the less volatile components get separated as a residue.

It is not like that distillate is completely more volatile and then residue is completely less volatile component. What do you mean by here? Let us say here 99% ethanol would be there and then 1% water may be there. 99% water would be there and then 1% ethanol is there. So, such kind of separation is possible if your feed is let us say 50% water and 50% ethanol was there. So, this separation is purely based on the relative volatility of the component that are present in the mixture.

Continuous fractionators are also possible. For high volume especially when you need high volume continuous separation of complex mixtures such as petroleum fractions, then continuous fractionators are used. Connect these with appropriate pumps, reboilers, condensers and automatic controls, etc. Pictorially it is shown here. Now here the feed is there, whatever is there let us say complex mixture of crude, petroleum crude. Then if you do the distillate, whichever component is more volatile in the crude that would be collected as the top distillate.

Whichever is the very least volatile that would not be evaporating easily and then that would be collected as the residue. Here again the temperature has to be selected based on the relative volatility and then boiling point of each of the component that are present here. So here in this fractionator in between you can also have the cut fractions also like this cut fraction 2, 3, etc. So, let us say one may be kerosene, another one may be diesel, another one may be petrol depending on their composition and then relative volatility, etc. Whether it is complex mixture or simple mixture, whether small quantity or high quantity whatever may be the reason, whatever may be the nature of the feed, the separation in distillation is based on the relative volatility of the components.

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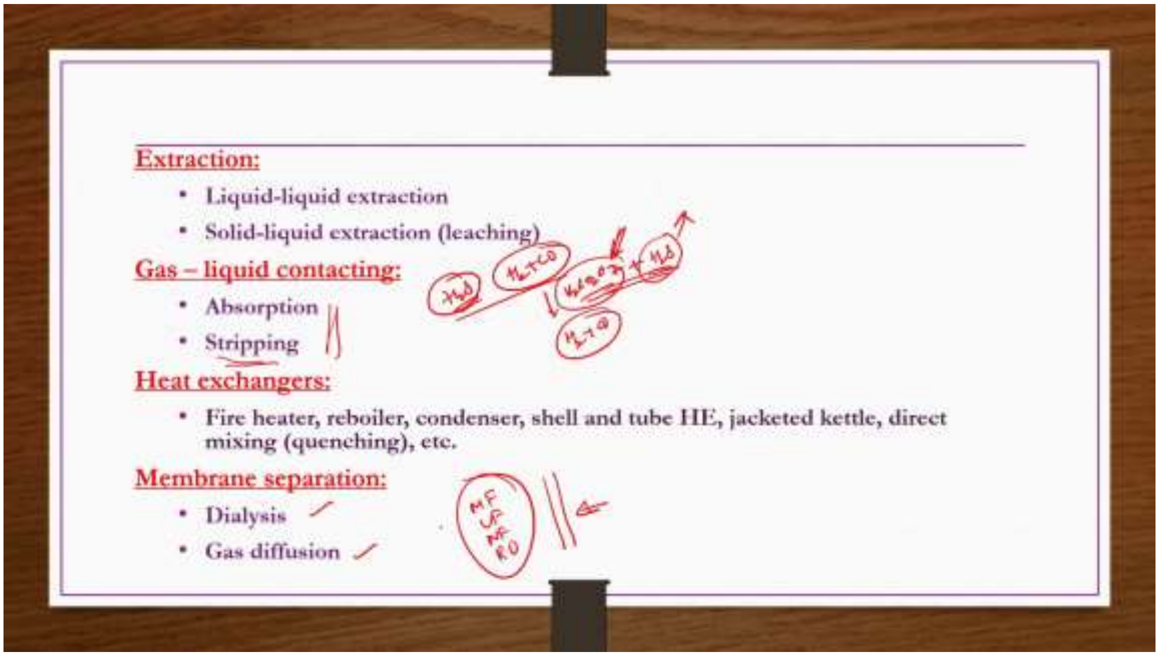

Then under extraction we have liquid-liquid extraction, solid-liquid extraction, we are not going into the details of them. Gas liquid contacting equipments also several are there, absorption. Let us say H_2S is there along with H_2 plus CO production. In the fuel gas production, you are trying to produce H_2 plus CO, but there is H_2S impurity is also there. So, what you do this mixture you pass through some solution, let us say potassium chromate solution.

So, this solution what we will try to do, it will try to absorb the H_2S only, the selection of the solution should also be such a way only and then you get pure H_2 plus CO, almost pure H_2 plus CO. So that is absorption of gas in a liquid is taking place, so that is known as the absorption. But now this $K_2Cr_2O_7$ potassium chromate solution is very expensive. Once it is diluted you cannot use for the other applications because it is diluted with H_2S, but you cannot throw it also because it is expensive. So, then what you do, the solution you heat it and then relieve this H_2S or remove H_2S from the solution.

Then you can recover this potassium chromate solution and then reuse for the subsequent batches of the absorption process. This removal of gases from the liquid solution is known as the stripping that is opposite to the absorption. So, absorption is absorbing the gas into the liquid, stripping is the removing the gas from the liquid solutions, okay? We are not going into the details of them because these things you study in your mass transfer courses. Heat exchangers, fire heaters, reboiler, condenser, shell and tube heat exchangers, jacketed kettle, direct mixing, etc., some of them are possible. Then membrane separations also, under membrane separations you have several like dialysis, gasification, you also have the microfiltration, ultrafiltration, nanofiltration, reverse osmosis, like that several operations are there where separation or purification is taking place. We are not going into the details of all these things, we are just listing some of the unit operations, okay? With this unit operations part is over.

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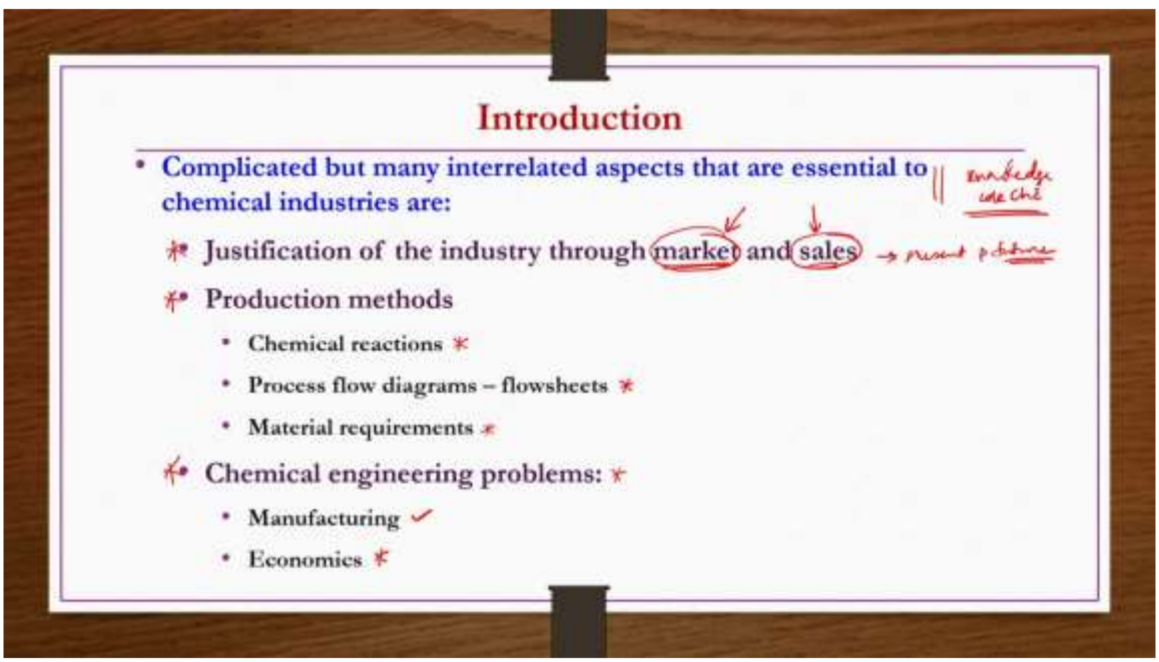

Now, we get into the main contents of today's lecture that is chemical process design, a few important information about chemical process design that is what we are going to discuss now, okay? There are many complicated but many interrelated aspects that are very essential from chemical industries point of view. Actually, having knowledge of core chemical engineering courses is not sufficient.

You need to have knowledge of additional things also. Let us say you need to have knowledge of a little bit about mechanical design aspects as well. You need to have knowledge about economics as well. You need to have knowledge about some maintenance related things as well. So, like that so many interrelated but complicated aspects are there, right? So, we need to have knowledge about all of these interrelated aspects of chemical industries. If you list a few of them, justification of the industry through market and sales, see.

Now, not only chemical engineering core subject knowledge, you need to have a knowledge about market, about sales also, right? If it is not having enough market whatever the product you are producing whether organic product or inorganic product or any other chemical product like polymer or you know petroleum or food, fertilizers, anything that you are producing, if it is not having market, then it is not going to be economically profitable for the industrialists. So, then market and sales are very important. These are only not from the present situation, but also from the future point of view also you should be able to anticipate how the market is going to be for a given product that you are going to produce in a plant. So, that knowledge is very much essential, okay? And then production methods. In general, there may be more than one number of production methods to produce a given organic chemical especially, right? There are many organic chemicals which can be produced by more than one method.

So then one should be careful, right? So, what are the reactions associated with those methods? You should be aware of such reactions as well. Then process flow diagrams, flow sheets. This is nothing but sequentially presenting what are the steps to be there in the plant, what are the steps or what are the unit operations and then unit processes and their combinations to be there in a sequential way you have to present and then realize what is the difference from one production method to the other production method, right? Then material requirements also. In some methods, you may not need a lot of materials, you just may need to have a reactants and then normal or nominal temperature, pressure conditions you are able to get. Some methods, there you may be needing to have extra steam, energy kind of thing, etc.

Those things are also be required in addition to the raw materials, etc. So likewise, what are the material requirements, etc., also you should have a knowledge. Then chemical engineering problems. This is the important part of the chemical engineers in general where manufacturing, how are you going to incorporate all these complicated interrelated aspects in the industrial level to get some product being manufactured. So that is very essential and then not only that one, how that product is going to be economical or profitable for the industrialist.

So, these things are very essential to understand from the chemical process design point of view. However, having the knowledge of all these subjects, it is not possible for one particular graduate engineer to able to handle all those things easily, right? So, for that reason what we have, we have different courses in undergraduate chemical engineering so that they would be helpful in sorting out these complicated interrelated aspects and in solving them so that one can produce chemicals smoothly at the industrial level.

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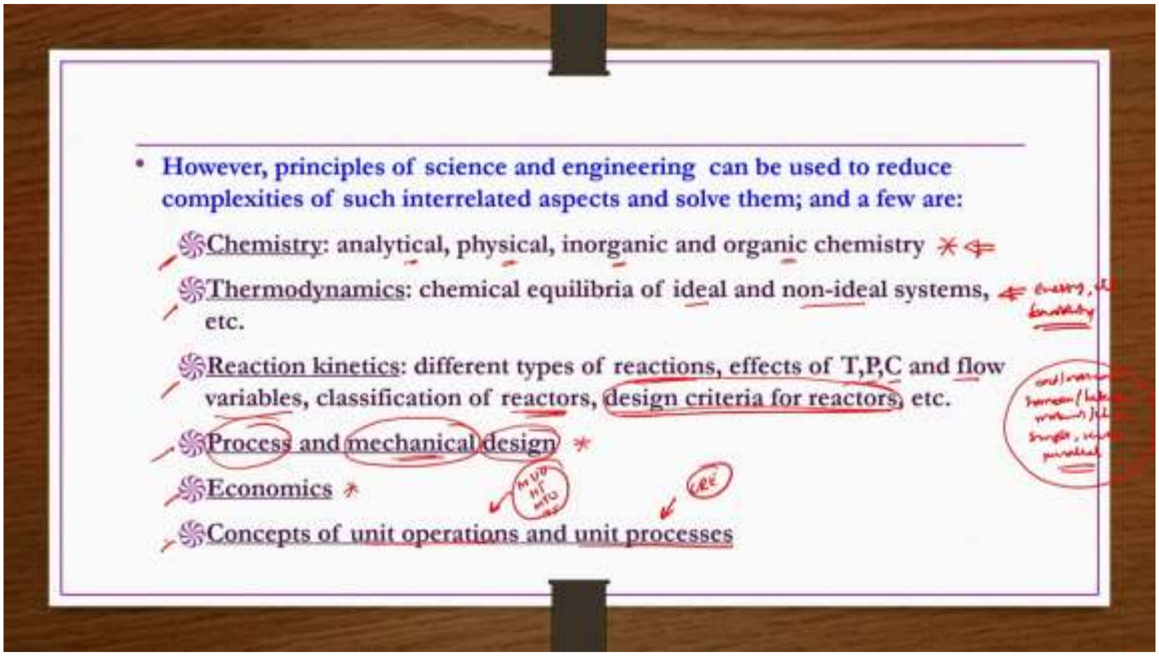

How that is possible? That is possible by applying the principles of science and chemical engineering, okay? So, principles of science and engineering can be used to reduce complexities of such interrelated aspects and solve them and then a few of those principles of science and engineering if you wanted to list. Basic chemistry, whether it is analytical chemistry, physical chemistry, inorganic chemistry, organic chemistry, you should have a thorough knowledge as per requirement of your plant, okay? Then thermodynamics.

Any plant more than one phase may be interacting. So how these phase interactions are there, you know, how the chemical equilibrium is being established between the phases, right? Whether these phases are ideal or non-ideal. So, all those thermodynamic equilibrium calculations will provide you knowledge about the energy requirements, etc., for the process to go and then also they may also give the feasibility knowledge whether the process is going to be feasible or not thermodynamically, all those knowledge you can get from the thermodynamics. Then reaction kinetics, different types of reactions are possible in general, right? Catalytic reactions, non-catalytic reactions, homogeneous reactions, and then heterogeneous reactions, molecular reactions, chain-initiated reactions, etc., okay? Then from the chemical reaction equations point of view, they can be simple reactions, they can be series reactions, they can be parallel reactions, like the different types of reactions are possible.

For your process, which kind of reactions are involved? So, you should be careful about them and then what are the effect of temperature, pressure, concentration and flow variables and transport properties on the overall kinetics of the reaction, that knowledge is also required. Then classification of reactors, which reactor is suitable for a given production method for a given reaction, which reactor is more suitable, batch reactor, semi-batch reactor, continuous homogeneous reactor or continuous heterogeneous reactor, all those details are required. Then design criteria for reactors, it is very essential, this has to be very carefully done because we already know that reaction should be considered as the heart of the process, so then that reactor design has to be very careful, right? So that design of the reactor has to be done very carefully. Then process design and mechanical design, in the design aspects what we have chemical process design, that includes like design of the unit operations, unit processes, etc. Also, there would be like mechanical design, where you have this construction related things, pillars related kind of thing and then those kind of mechanical related design aspects comes under mechanical design aspects.

So those things we are going to see. Then also economics, knowledge of the economics is required for the plant for a given investment, how much is the return that you should be able to calculate by considering all economic factors, okay? At least that much knowledge of economics is required for the chemical engineering graduates. Then concepts of unit operations and unit processes, these unit operations you study in mechanical unit operations, heat transfer course, mass transfer courses, transport phenomena, etc. Here you study more details about unit operations and then more details about unit processes in general you study in chemical reaction engineering related courses, etc., right? So, if you have the knowledge of chemistry, thermodynamics and then reaction kinetics, process and mechanical chemical process and mechanical design and then economics and then concepts of unit operations and unit processes, then you can segregate or separate the interrelated these complicated problems of the chemical industries and then you can easily solve them and then have a complete chemical plant which could be giving profitable product, right?

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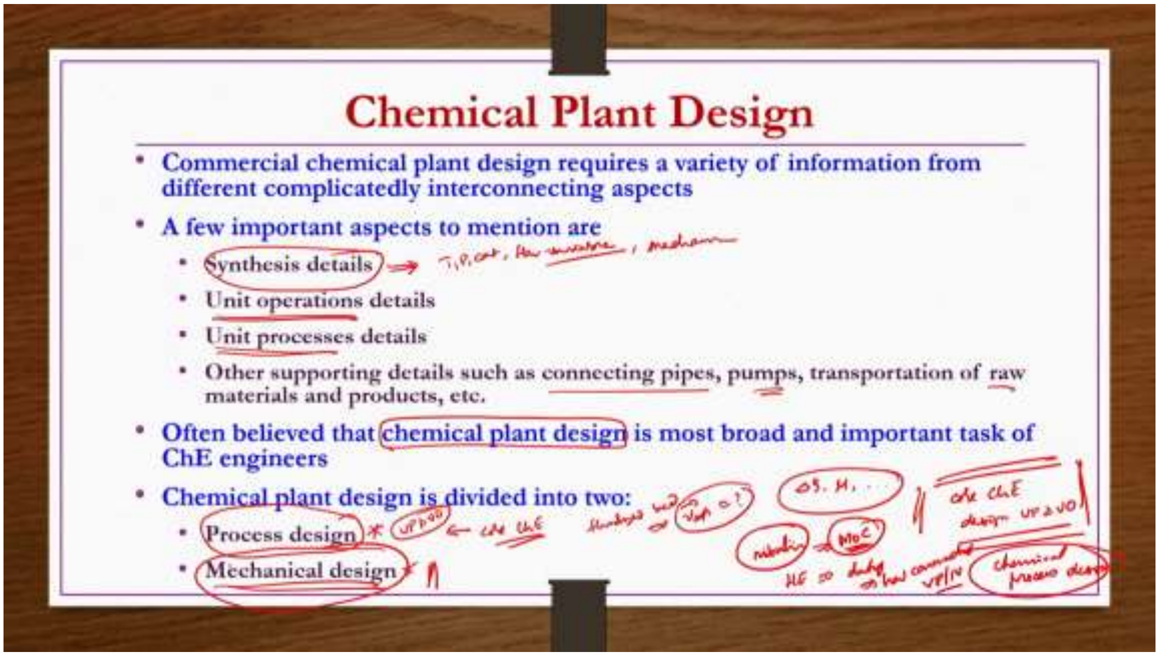

Now we see chemical plant design. Commercial chemical plant design requires variety of information from different complicated interconnecting aspects as just discussed.

A few important aspects to mention again here are synthesis details, unit operations details, unit processes details, other supporting details such as connecting pipes, pumps, transportation of raw materials and products, etc., okay? So, all these details are required, okay? So, synthesis details usually you get from the laboratory scales, okay? How the given chemical is being produced in the laboratory, what are the temperature, pressure conditions, what are the catalyst required, what are the flow variables or the transportation property, effects, etc., those things you get under synthesis details, right? Reaction mechanism, etc., all those things you get from the synthesis details. Then unit operations details, what are the unit operations required for the reactants to be make ready for the reaction to undergo.

After the reaction, what are the unit operations required for the purification of the products, etc., or separation of the products, etc., then unit processes, how these unit processes are incorporated, what kind of the reactions are there, what kind of reactor should be used, all those details are required. In addition to these things, you need to have the connecting pipes from one unit operation to the other unit operation or unit process, there may be connecting pipes, in fact, there would be connecting pipes, how are they connected, those details and then pumps for the transporting the fluids, you need to have the pumps for the transportation of the solids unit, you need to have the elevators, bulk elevators, etc., screw conveyors, etc., or maybe other kind of solid conveying equipments, etc., also required. Then also transportation of materials, whether it is raw material or product, for those information also required, okay? So, chemical plant design is believed to be the most broad and important task of chemical engineers in general and then this chemical plant design is divided into 2 categories, one is the chemical process design where mostly you talk about the design of unit processes and unit operations, etc., and then mechanical design where you talk about the construction of equipment and all those additional kind of details you discuss in the mechanical design. So, especially all these process design related things you complete in other core chemical engineering courses in general, right? Let us say you are using fluidized bed reactor, right? What should be the minimum fluidization velocity, right? That you can calculate, how to calculate those things we already know depending on the delta rho and then mu, all these properties of the fluid and solids which are interacting, you can calculate what is the minimum fluidization velocity, etc. So, like that for almost all unit operations you can get design parameters from your core chemical engineering courses, okay? Similarly, for unit processes also you will be able to calculate all the design related aspects whatever the kinetics, what are the energy requirements, all those things you would be able to calculate from your core chemical engineering courses point of view, right? So, basically if you have the core chemical engineering knowledge, you will be able to design any unit operation or any unit process without any difficulty. So, whatever you learn in these courses like heat transfer, mass transfer, mechanical unit operation, etc., all they come under chemical process design, but that itself is not sufficient. You need to have the knowledge about mechanical design. Let us say for a given nitrogen reaction, assume there is a nitrogen reaction, so what is the material of construction of the equipment or the reactor? That you should know. You have heat exchanger, right? What is the duty of heat exchanger and then how connecting within a subsequent unit operations or unit processes has been, all those things additional details may be coming from this mechanical design aspects point of view, okay?

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Design aspects of unit operations and unit processes are part of process design as I mentioned, whereas the construction of equipment, foundations, buildings, process acceleraries, installation operation, maintenance, etc., are all part of mechanical design. So, mechanical design you will be learning how to decide the construction of equipment, foundation, etc., all those things you learn from the mechanical design courses, okay? Whereas the design of unit operations and unit processes you will learn from the core chemical engineering courses. But however, there is a considerable overlapping between process and mechanical design in general. So chemical engineers are having major role in solving design problems because of such kind of overlapping, okay? Now process design, we start discussing about the process design only.

Mechanical design we are not going to discuss. We are discussing only process design. Role of R&D on chemical process is to provide sufficient and complete information to prepare series of flow diagrams. When you start a design of a plant, you select the product which is profitable and then for that methods of production you select based on the primarily economics and then safety point of view. And then these methods of production several steps would be there, right? So, these several steps include several unit operations and then unit processes. Sequentially you have to present them to understand the process, the sequential presentation of these unit operations and then unit processes to get the required production of chemicals, whatever the process is there that is known as the flow sheeting, right? Okay? So, these flow diagrams are also known as the flow sheets.

These flow sheets include several unit operations and unit processes to achieve desired production. Usually process design include flow sheets, process steps and then design steps. So now we are going to talk about these 3 aspects before going into the economics aspects of a chemical plants.

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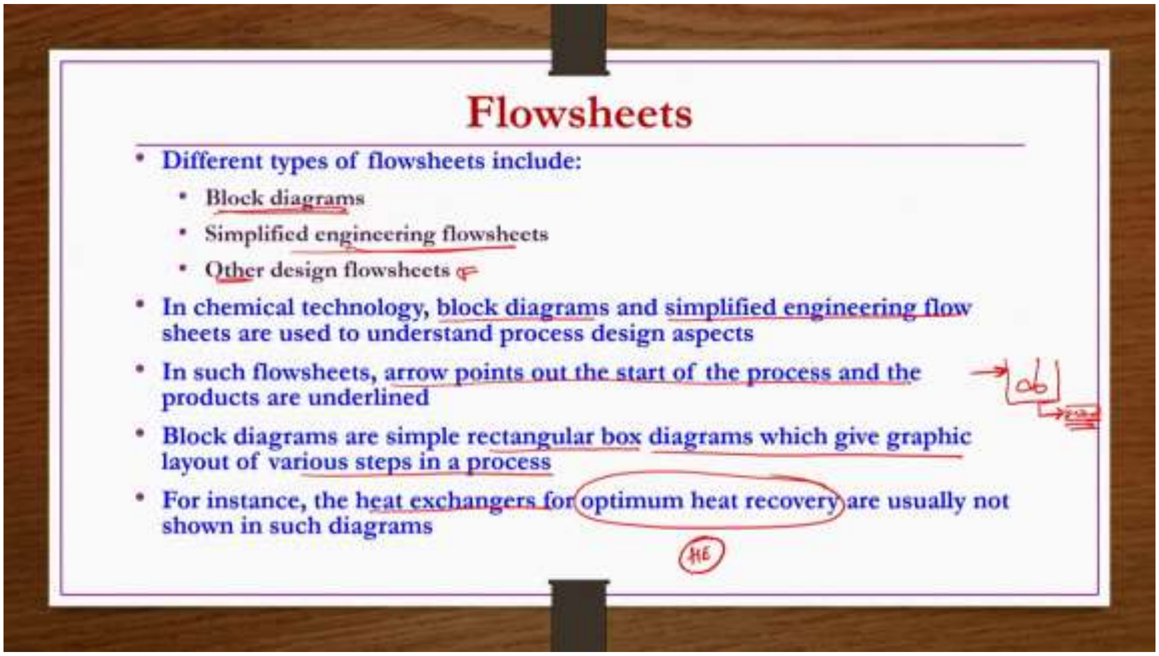

So, let us start with flow sheets. Different types of flow sheets are possible. The basic one is the block diagrams flow sheet. Next one is the simplified engineering flow sheets. The third one is other design flow sheets. Other in the sense let us say you need some piping layouts, you need some electrical layouts, etc., or you need instrumentation layouts, etc., required. So, all those things come under this other design aspects or other design flow sheets, okay? So, what are these block diagrams? Block diagrams is nothing but whatever the sequence of unit operations and then unit processes are there in the plant to produce a given chemical. So that you present in simple boxes kind of thing without giving much information about material energy balance, stream quantities, etc. So, then we call them block diagrams. Simplified engineering flow sheets are improved over block diagrams where you give these specific shapes for a particular unit operation and then particular unit process like that and not only that one you also give the temperature, pressure conditions as well as the material energy balance.

All those details are provided in simplified engineering flow sheets. Those details we see anyway. In chemical technology, block diagrams and simplified engineering flow sheets are used to understand process design aspects. In such flow sheets arrow points out the start of the process and the products are underlined. Let us say here you have the batch reactor and then whatever the material that is coming into this reactor, so the arrow points out the start of the process like this, okay? And then let us say whatever the product is coming, the product whatever you got that is underlined, products are underlined usually, okay? These are a few conventions that are being followed in chemical plant design aspects. Block diagrams are simple rectangular box diagrams which give graphic layout of various steps in the process.

For instance, the heat exchangers for optimum heat recovery are usually not shown in such block diagrams. Wherever heat exchangers are there, it is a very good example of optimizing the sizing of an equipment, right? So, several aspects are there. So, all those details are not provided in block diagrams in general.

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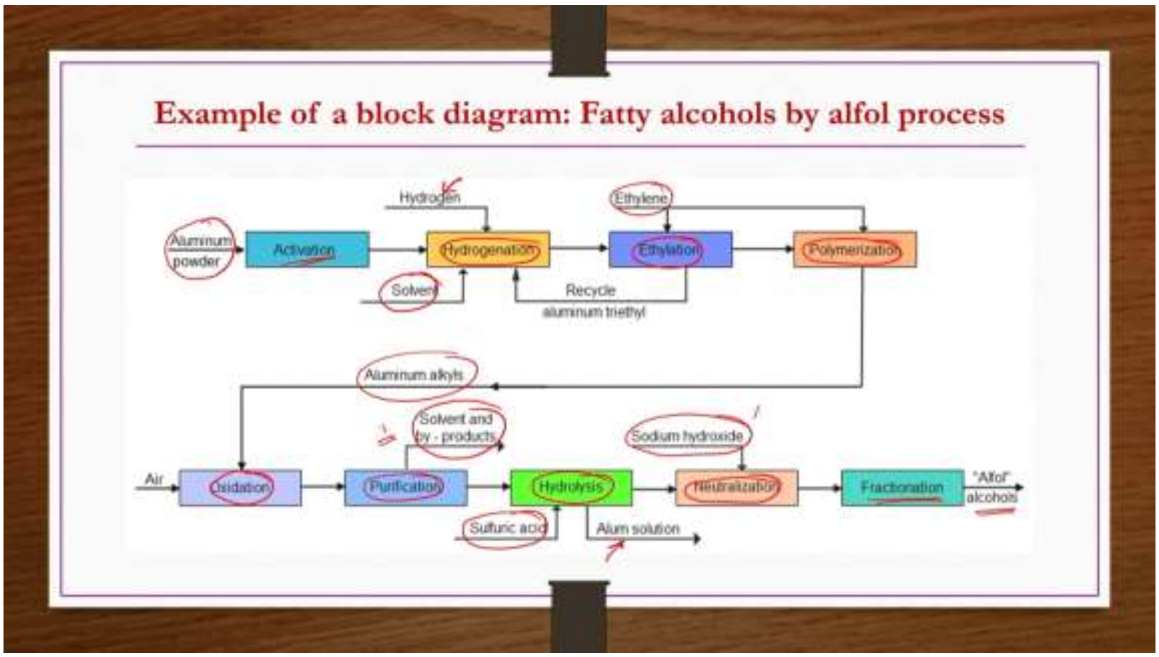

Now if you take an example of a block diagram where fatty alcohols by all fall processes are being produced. So now here see, aluminum powder is taken and then it is activated. How it is activated, at what temperature, what is the reactor, all those things are not mentioned, just in a box it is provided.

Then whatever the output is coming after the activation that is being hydrogenated using the hydrogen, what is the flow of hydrogen, at what temperature pressure it is coming, itis not mentioned, right? Also, there is a solvent requirement for this hydrogenation, those things are also not provided, okay? Details of those solvents are also not provided, conditions are not provided. Like that subsequent steps of ethylation, polymerization, etc. are taking place, right? Here for ethylation, ethylene is being added up, that is what mentioned and nothing else. Nothing is mentioned, what kind of reactor, etc., polymerization, what kind of polymerization, all those things, nothing is mentioned. And then all these processes or steps, they are shown in rectangular boxes only, right? Otherwise for pumps, specific shapes are there, for batch reactors, specific shapes are there, cyclone separators, the specific shapes are there, for fluidized bits separate specific shapes are there. Some of them we have seen in previous lecture on unit operations as well. So, such kind of specific shapes of unit operations or unit processes are not shown here in the block diagram, not only missing the information about the quantities entering, temperature, pressure, etc. Also, the representation is also done in rectangular boxes only, okay? So whatever polymerized aluminum alkyls are there, they have been further oxidized using air, then purification has been done where the solvent and byproducts are removed. What is the percentage of solvent and byproducts being removed that is not mentioned, okay? So then further purification is done.

After the purification, hydrolysis has been done using the sulfuric acid where alum is forming so that alum solution is being discarded. After discarding the alum solution, neutralization has been done because sulfuric acid has been used. For neutralization, sodium hydroxide is used. What is the purity of sodium hydroxide, what quantity required that is not shown, right? After the neutralization, fractionation is done so that to get all alcohols product.

So here no details are available except the steps of the process or the steps of the plant, nothing is been provided. Those steps also represented in the rectangular box. So, such kind of representation is known as the block diagram, okay?

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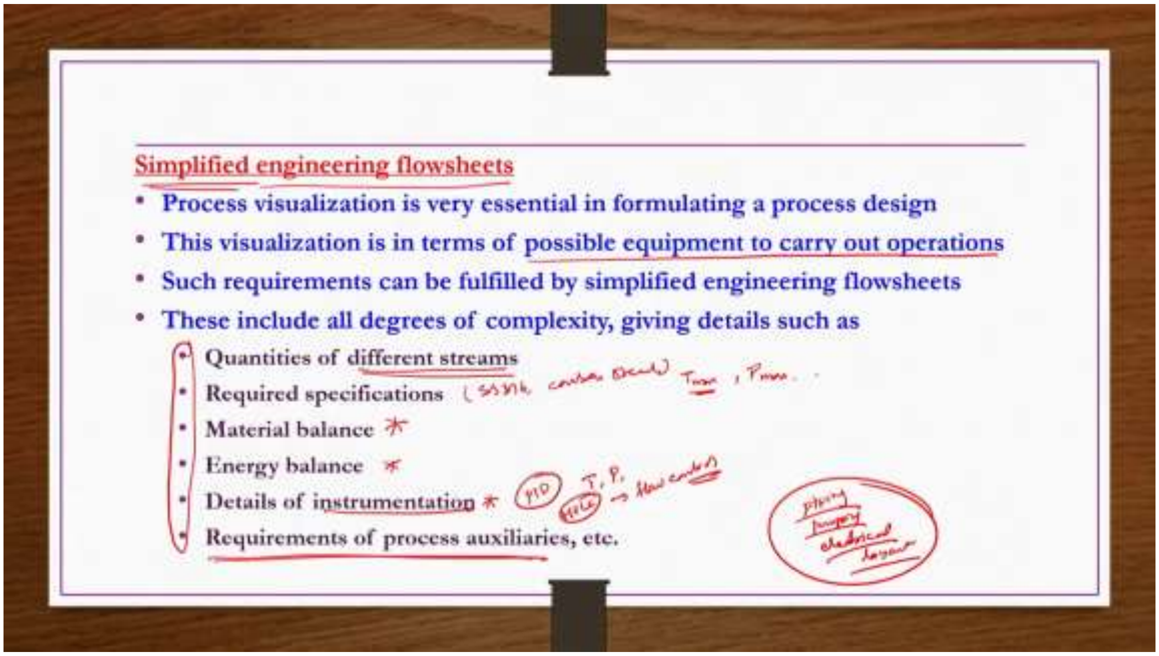

Whereas in simplified engineering flowsheets, more details are provided in general. We see those things, okay? A proper visualization of the process is very essential in formulating a process design and then such visualization is in terms of possible equipment to carry out operations. Let us say hydrogenation is to be done, which is the best reactor to do the hydrogenation? What is the temperature, pressure condition for that hydrogenation? Is there any catalyst? What kind of catalyst? All those details should be available in the flowsheet only and then such details we provide in the simplified engineering flowsheets, okay? Such requirements can be fulfilled by simplified engineering flowsheets. These include all degrees of complexity giving details such as quantities of different streams, required specifications, specifications in the sense reactor which reactor is made of SS 316 or what or any other metal, carbon steel.

Like that you know not only the material of construction specification, other specification, what is the maximum temperature up to which that particular unit process or unit operation should be operated, what should be the maximum pressure, etc., those kind of details required specifications is also provided and different streams also provided. What flow rate reactant should be coming into the reactor? What is the purity of the reactants? What are the products going out of the reactor? How much percentage of product stream is being sent back to the reactor as a recycle if at all it is present? So, all those quantities are also provided in general in simplified engineering flowsheets. Material balance is also provided, energy balance is also provided, details of instrumentations also provided like PID controller, let us say if you wanted to control temperature, pressure, and then if you have HPLC pumps, etc., then also flow controllers are there. So, all these things you know controlled by some kind of instruments. So, details of instrumentation should also be provided in the flowsheets. Requirement of process auxiliaries like you know piping, pumping, and then electrical layout, etc., also sometimes required. So, they should also be provided. Often, they are not provided, but sometimes you know requirements are shown, not the details of piping, but requirements of piping, requirement of pumping should be shown, okay? So, it is an engineering flowsheet because engineering details especially chemical process, design calculations, whatever you do those details are you know being provided in the flowsheet, but still not all the details are being provided.

That is the reason though these are engineering flowsheets, they are called as simplified engineering flowsheets because if you put everything in one flowsheet, it will become very complicated, very difficult to understand the engineer. Let us say after one engineer, other engineer is taking over the plant, so then it will become very difficult for him to understand, okay? So, that is the reason this simplified engineering flowsheet will provide as much information as possible without making it complicated, but however, additional information whatever are required like you know piping layout, electrical layout, instrumentation layout, etc., those things are separately provided through other design layouts, okay?

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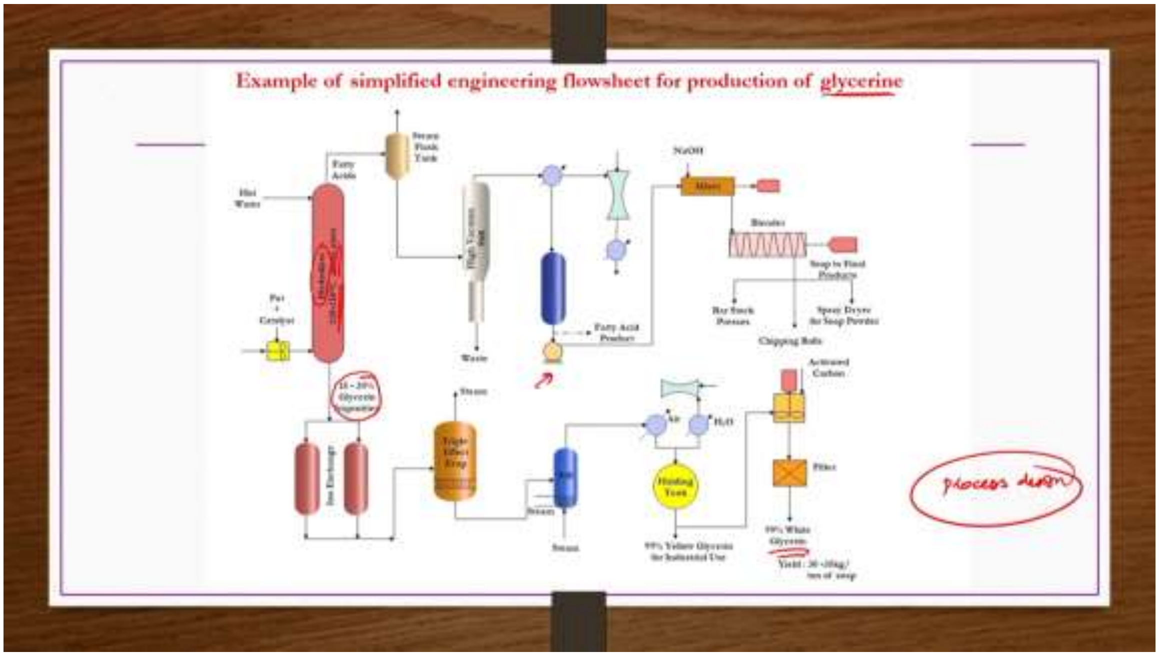

Before going into those other design layout, we will see an example of simplified engineering flowsheet here which is for the production of glycerin. Now here see, hydrolyzer is there, what is the temperature at which it is operating, what is the pressure at which operating is provided and then what are the glycerin impurities are there, those things are shown here. Like that you know pump requirement is there that is shown, right? So, like that you know you see in this process, so many details have been shown, you know most of them are kind of engineering details, okay? So most of the process design details are shown here, right? So, this is an example of a simplified engineering flowsheet.

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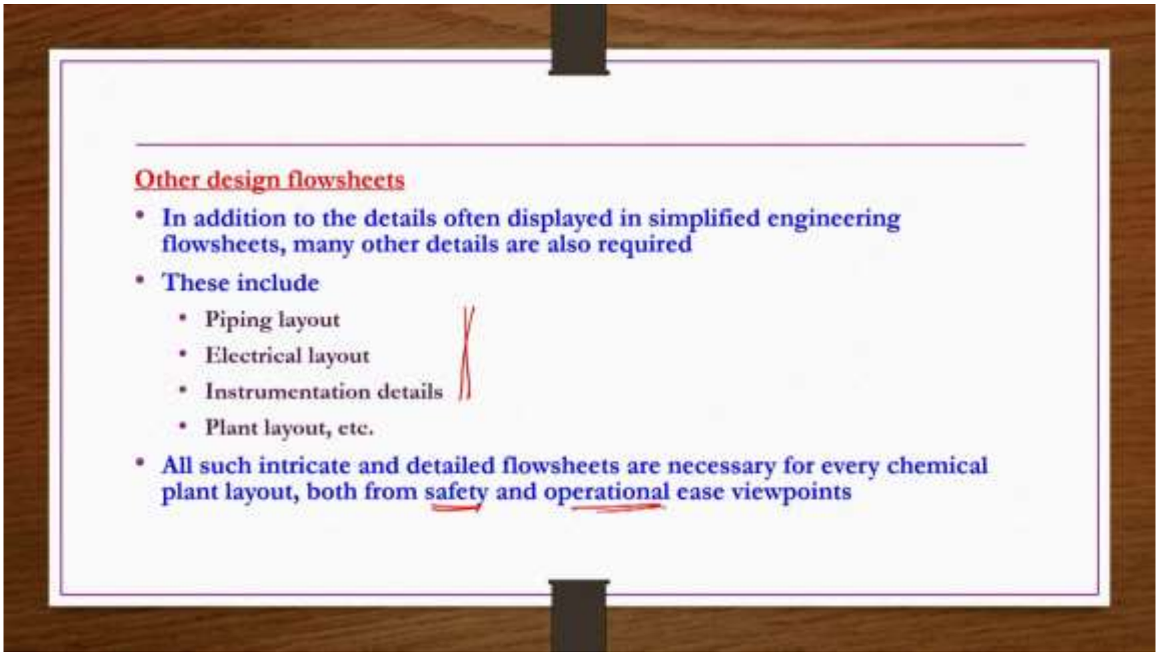

Now other design flowsheets as I mentioned in addition to the details of often displayed things in simplified engineering flowsheets, many other details also required. These include piping layout, electrical layout, instrumentation details, they are separately provided apart from the simplified engineering flowsheets. Plant layout is also required. All such intricate and detailed flowsheets are necessary for every chemical plant layout both from the safety and operational ease point of view, okay?

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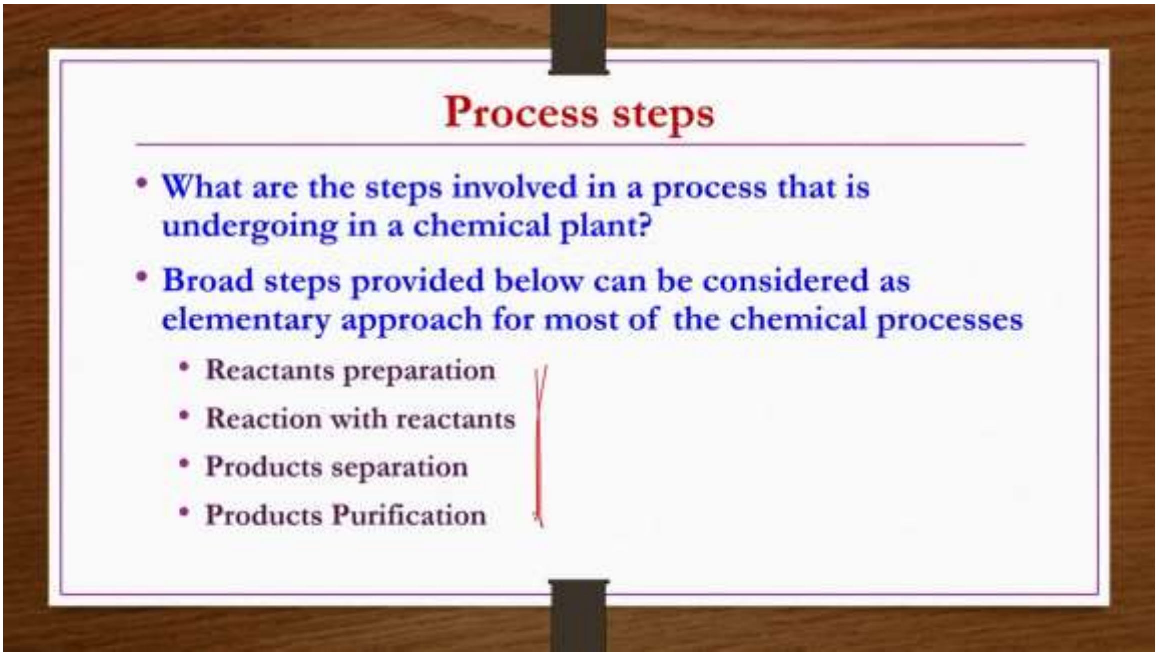

Now after discussing the flowsheets, we will discuss about the process steps.

What are the steps involved in a process that is undergoing in a chemical plant is very essential to know. Broad steps provided below can be considered as elementary approach for most of the chemical processes, something like reactants preparation, then reactions with reactants, then separation and purification of the products. These kind of steps are very common in process steps.

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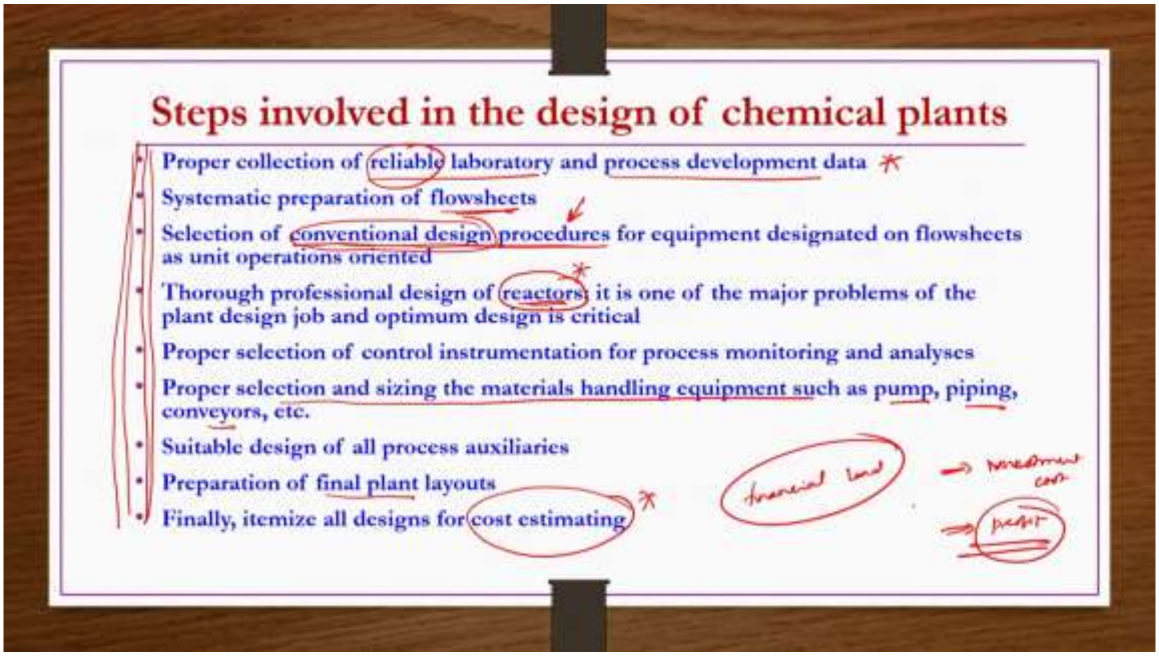

Steps involved in the design of chemical plants if you wanted to see, there are many steps are there.

First and foremost, important one is the data. Which data? Reliable laboratory data and then process development data. They should be collected and they should be reliable because based on this data only you are going to develop the plant. If this data is not reliable, so then your plant is not going to be profitable, okay? So, this data has to be very reliable. Then systematic preparation of flowsheets. Once you have the process, you know what are the steps or the unit operations or unit processes or both are going to be involved in the process.

So systematically presenting them in a flowsheet manner. Just put them in a block diagram thing, then you develop a simplified engineering flowsheet, then other design aspects also include like that systematic preparation of flowsheets is required. Then design of unit operations and unit processes. How to design? What should be the basis for the design consideration? So, for the design of a unit operations often it is better to go for conventional design procedures for equipments, right? Why conventional? Because you know these are chemical plants are very risk oriented. If they are not successful, so then there is going to be huge loss that from the economics point of view. From the safety point of view also if there is any loophole or missing information while designing then or any mistakes occurring, so then that is going to be very dangerous from the safety point of view also.

However, conventional design processes you know mostly they are foolproof, so then it is better to go for the conventional design processes for the equipment of unit operations as well as the unit processes as well. And then thorough professional design of reactors also very much essential because reactors in the chemical plants reactors are very important things, right? Based on the efficiency of the reactors you know product yield and profit are going to be affected, okay? So, it is one of the major problems of the plant design job and optimum design is very critical. Then proper selection of control instrumentation for process monitoring and analysis. Then proper selection and sizing the materials handling equipment such as pump, piping, conveyors, etc.

All these informations are required. Suitable design of all process auxiliaries, preparation of final plant layouts and then finally itemize all designs for cost estimating. You have all these steps, all these details and then for each of these things you know what is the financial load. You put them together that will give you investment cost. So, based on investment cost how much profit are you getting or what is the return for a given investment that you have to calculate.

Once you find it is going to be profitable then you can put it in the field for the realistic production of the chemicals. All these things should be done on papers before start of any plant and then make sure it is going to be profitable.

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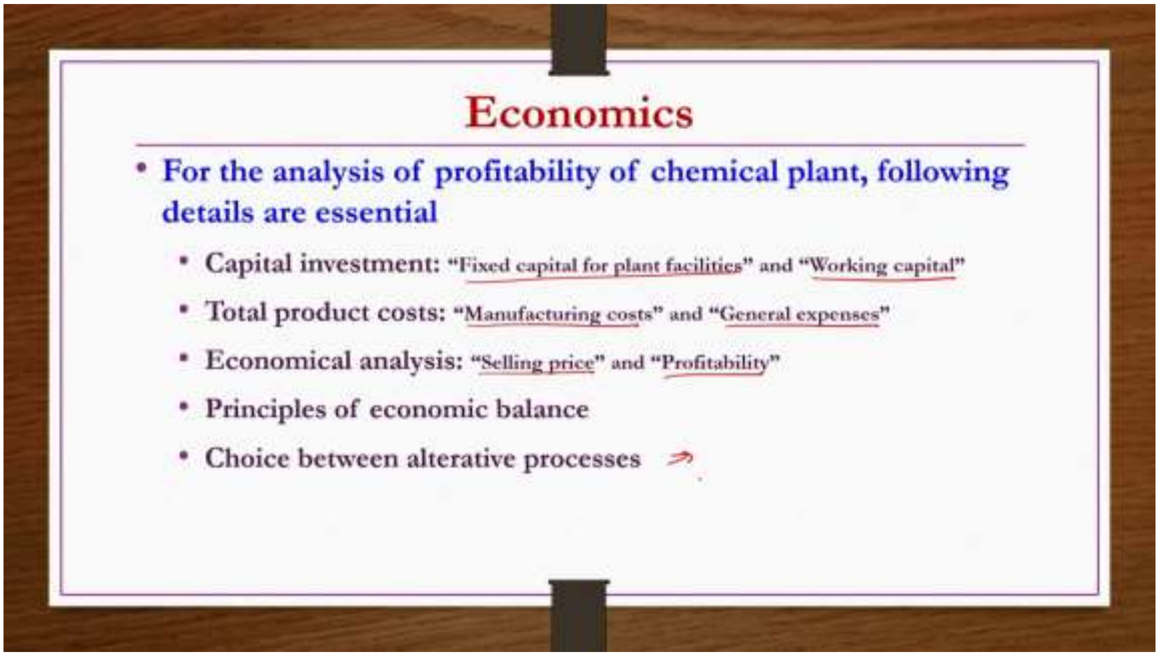

Now we see a few details about economics. For the analysis of profitability of chemical plant following details are very essential. First one is the capital investment where you have fixed capital for plant facilities and then working capitals as well.

Then total products cost where you have manufacturing cost as well as the general expenses. Then economic analysis should be selling price versus profitability. Then principles of economic balance is required. Also, choice between alternative process as I mentioned for majority of organic chemicals more than one process may be available.

You have to choose the one which is more profitable.

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Now we see individually about these economic details as well. Under the capital investment as we have seen two components are there, fixed capital for plant facilities and then working capitals. Fixed capital for plant facilities includes site, site cost, buildings, utilities, process equipment, storage facilities, auxiliary utilities and emergency facilities. All these things come under fixed capital for the plant and then under working capital it includes raw materials inventory, in process inventory, product inventory, then maintenance and repair inventory, accounts receivable, credit, carryover and minimum cash reserve all these things comes under working capital.

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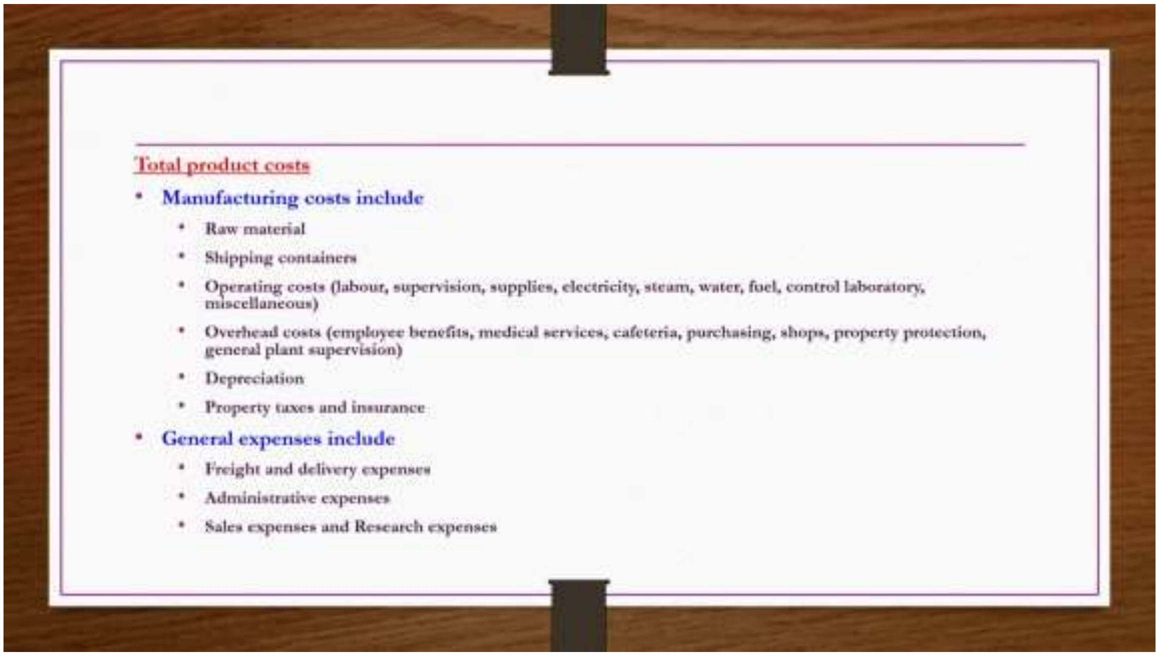

Coming to the total product cost you have manufacturing cost and then general expenses. Under the manufacturing cost you have the cost of raw materials, shipping containers, operating cost for the labor, supervision, supplies, electricity, steam, water, fuel, control laboratory, miscellaneous all those costs comes under operating cost and then overhead cost something like employee benefits, medical services, cafeteria, purchasing shops, property protection, general plant supervision, etc. comes under the overhead cost. Then depreciation, property taxes and insurances all that comes under manufacturing cost only. Under the general expenses of total product cost, you have the freight and delivery expenses, administrative expenses, sales and research expenses, etc.

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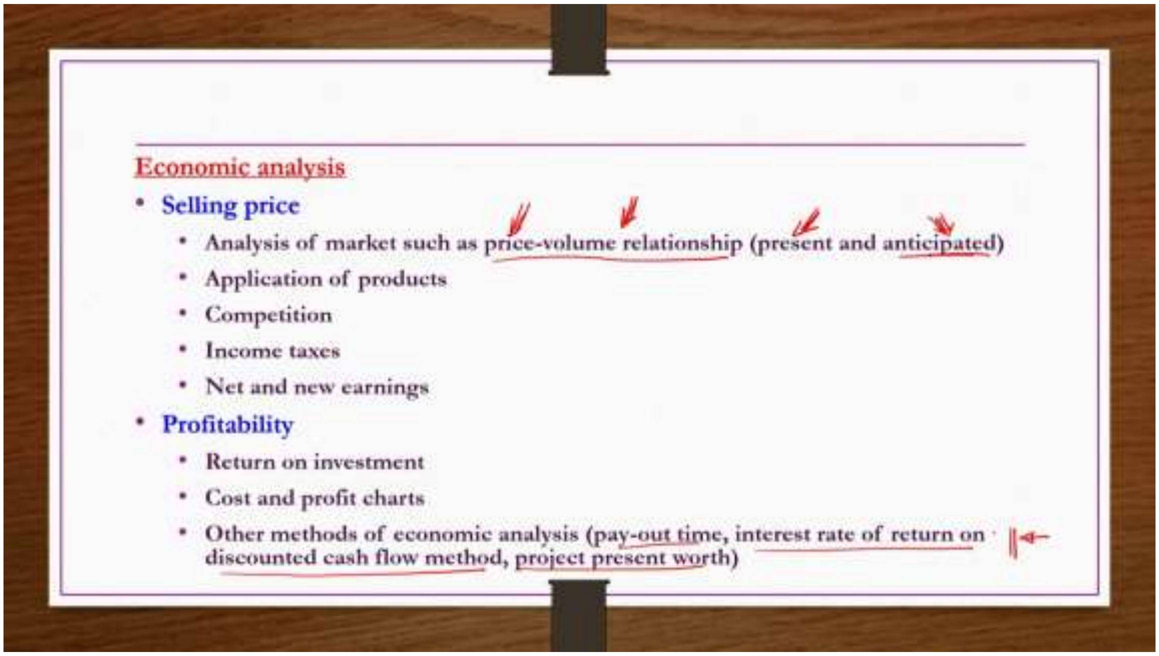

Third one is the economic analysis. Here two things are there, one is the selling price another one is the profitability. Selling price, analysis of market such as price volume relationship is required.

So how much quantity if you produce that would be sold out that is again important and at what price. So that information not only based on the present market situation but also anticipated for the future market also that you should able to do. Then application of products, what are the applications of the products? If one product is having multiple application then obviously it is going to be have more market and then value. Price versus volume relationship may be good for such kind of thing. Then competition, how many other brands are producing the same product? How good are those companies or industries doing business? All those things you have to see and then put them under the competition head.

Then income taxes, net and new earnings, etc. you have to analyze. Under the profitability return on investment how much? You have to include all the costs like capital cost and then total production cost, etc. Everything you include and then you put them under investment. For a given investment how much return are you getting and then within how many months or years are you able to recover the capital cost, etc. All those things also you have to calculate. Cost and profit charts you have to prepare and then other methods of economic analysis also possible like payout time, interest rate of return on, discounted cash flow method, project present worth method, etc.

But these things chemical engineers cannot become experts until specially they read about these subjects.

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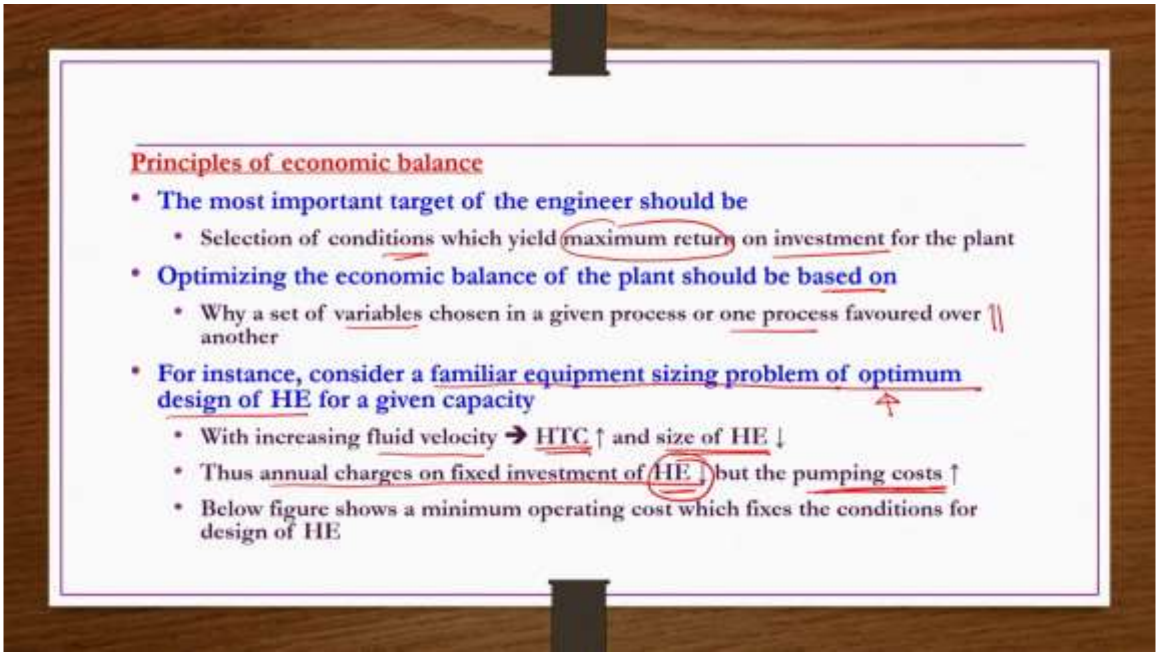

Then principles of economic balance which is very essential. The most important target of the engineer should be the selection of conditions which yield maximum return on investment for the plant and then optimizing the economic balance of the plant should be based on what point. Let us say why a set of variables chosen in a given process or one process favored over another one you should be able to understand. So, then you can answer the optimizing the economic balance. For instance, if you consider a familiar equipment sizing problem of optimum design of heat exchanger which is maybe there for almost all chemical plants, then you can understand this economic balance importance.

Often heat exchangers let us say shell and tube heat exchanger if you take there is a shell and there is a kind of tubes like this. So now, under the shell one fluid may be flowing at certain temperature and then going out at certain temperature. Under the tube one fluid is coming under certain temperature and then going out and certain temperature out. So, this temperature difference is going to be very essential.

Without interacting two fluids are exchanging the heat. So here the flow velocity or the fluid velocity is there. So that is very essential very important in general. Let us say if you increase the fluid velocity heat transfer coefficient increases which is good from the process point of view, but the another important is that if you have the higher fluid velocity then size of the heat exchanger also decreases that is also good. But because of that one annual charges on fixed investment of heat exchangers decreases that is again good, but the pumping cost that increases.

But the pumping cost increases. So, then you have to make a tradeoff between these two. So below figure shows a minimum operating cost which fixes the conditions for design of heat exchanger. Such kind of optimization should be done for almost all equipment and an entire plant in general.

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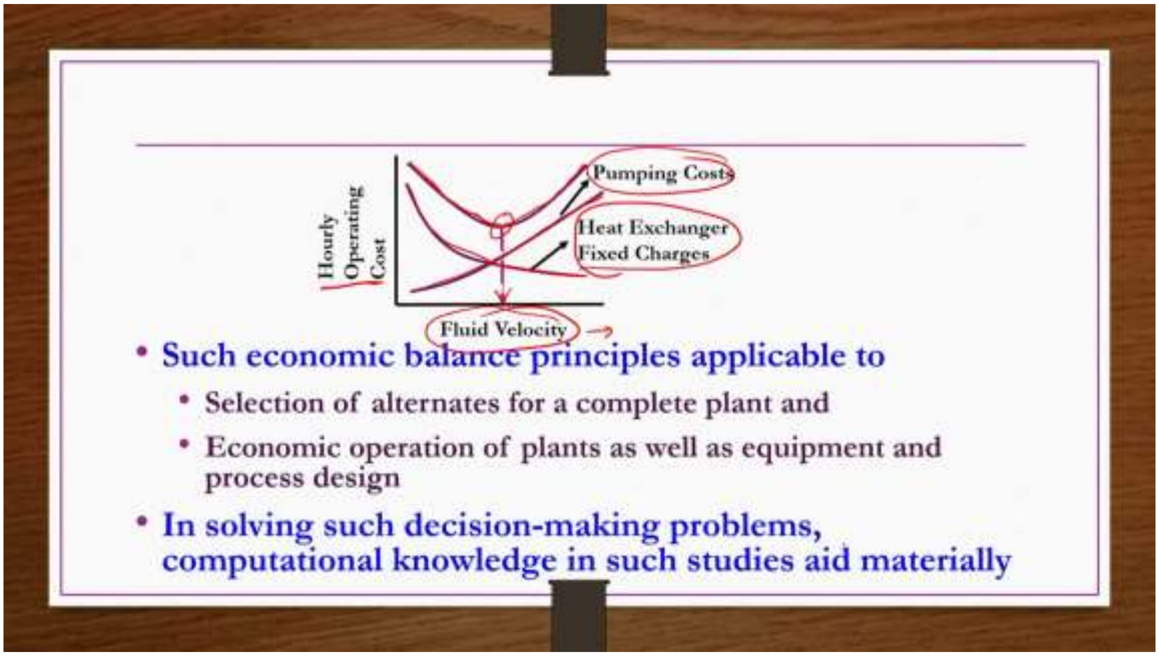

Let us say if you take hourly operating cost versus fluid velocity for a heat exchanger then as you increase the fluid velocity heat exchanger fixed charges are decreasing gradually. But again, by gradually increasing the fluid velocity what happened the pumping cost are increasing exponentially.

If one is positive another one is the negative. So, you combine together and then you draw then you have a curve like this with increasing the fluid velocity hourly operating cost decreases up to certain velocity and then again further increasing the velocity it increases. So, corresponding to the point where the minimum is there that should be taken as the fluid velocity and then accordingly the pumping cost and then heat exchanger fixed charges you have to take which is going to be optimum one. Such economic balance principles applicable to selection of alternates for a complete plant and economic operation of plants as well as equipment and process design.

In solving such decision-making problems computational knowledge in such studies usually useful.

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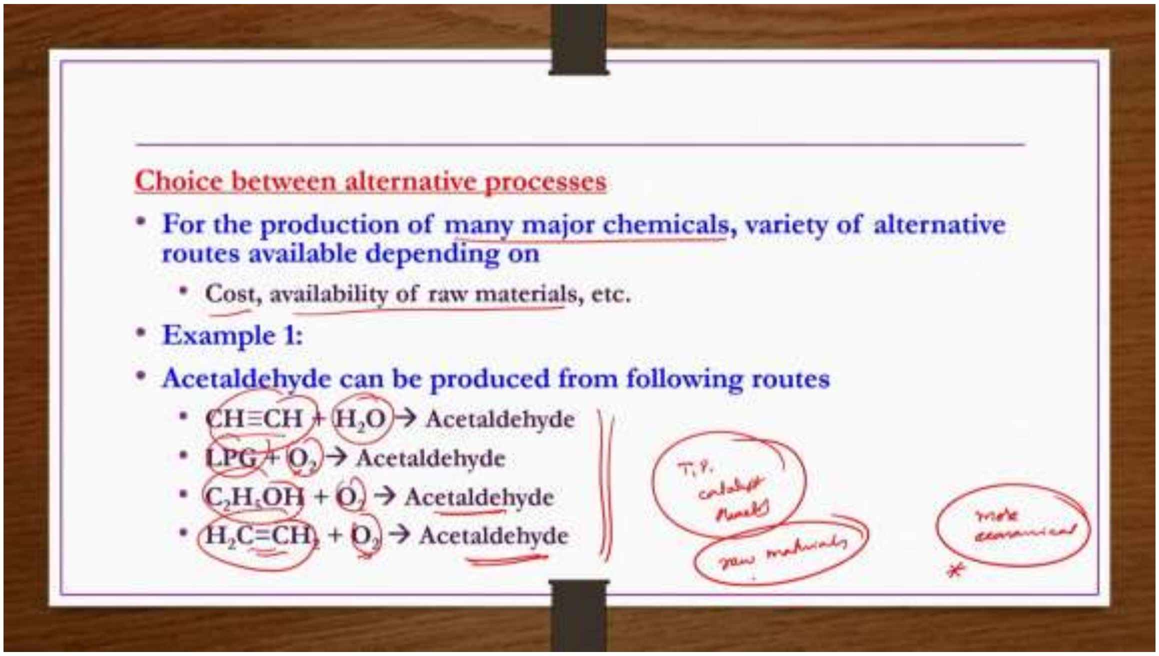

Now the last point is the choice between alternative processes. If there are multiple processes to produce one particular chemical. So, then you have to choose the one which is more profitable and then more safe. So, for the production of many major organic chemicals especially variety of alternative routes available depending on cost availability of raw material, etc. you have to select the appropriate one. Let us say example one if you take acetaldehyde that can be produced from following routes. One is the hydration of acetylene if you do then acetaldehyde you can produce. If you do the oxidation of LPG then also acetaldehyde you get as one of the product. Then oxidation of ethanol also provides acetaldehyde. Ethylene you take and then you do the oxidation then also you get the acetaldehyde.

So, a hydration reaction oxidation reactions are possible different raw materials are there. So then obviously different temperature, pressure, conditions and then catalyst then reactor type etc. all those things would be there and then availability of raw materials how closely are available. The raw material may be sometimes cheaper but you know transportation cost if it is very high since you are getting from the faraway place it is not going to useful. So, all such kind of things you have to consider and then select a process which is going to be more economical if you have alternative processes.

So more economical one you have to choose and then how do you choose more economical one you have to consider all the points mentioned under the economics of the plant. Just few slides before we discussed all those costs you have to include and then see which is going to be more economical and then that one you have to choose.

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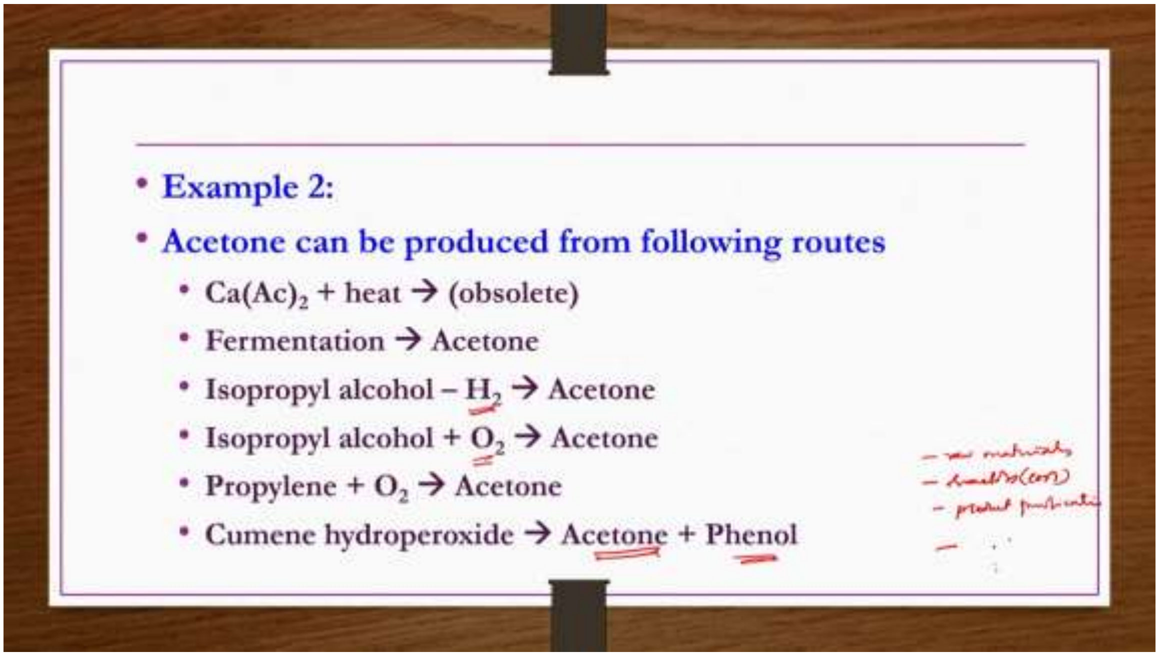

Likewise, other examples like you know acetone that can be produced like if you have the calcium acetate you heat it then obsolete acetone you can get. In the fermentation also, acetone you get as one of the product. Then isopropyl alcohol you have so either you do the dehydrogenation or you do the oxidation then you get the acetone as the product.

Propylene oxidation also give the acetone, cumene hydroperoxide also if you decompose you get the acetone and phenol. So here also you know you have to list out availability of raw materials, etc. Reactors, cost, etc. all those cost, etc. you have to include and then product purification also important.

Sometimes you have the product but purification sometimes you may produce the product with less cost but purification of the product may be more expensive. So, all those things you have to list out and then see more economical process whichever is there that you have to use.

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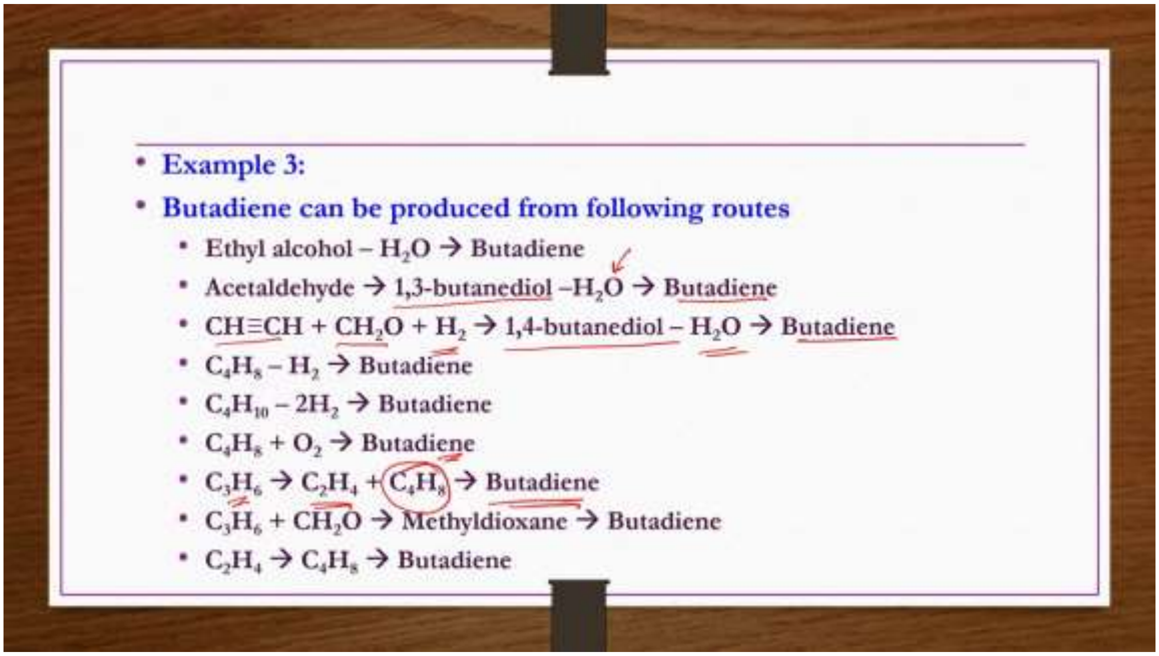
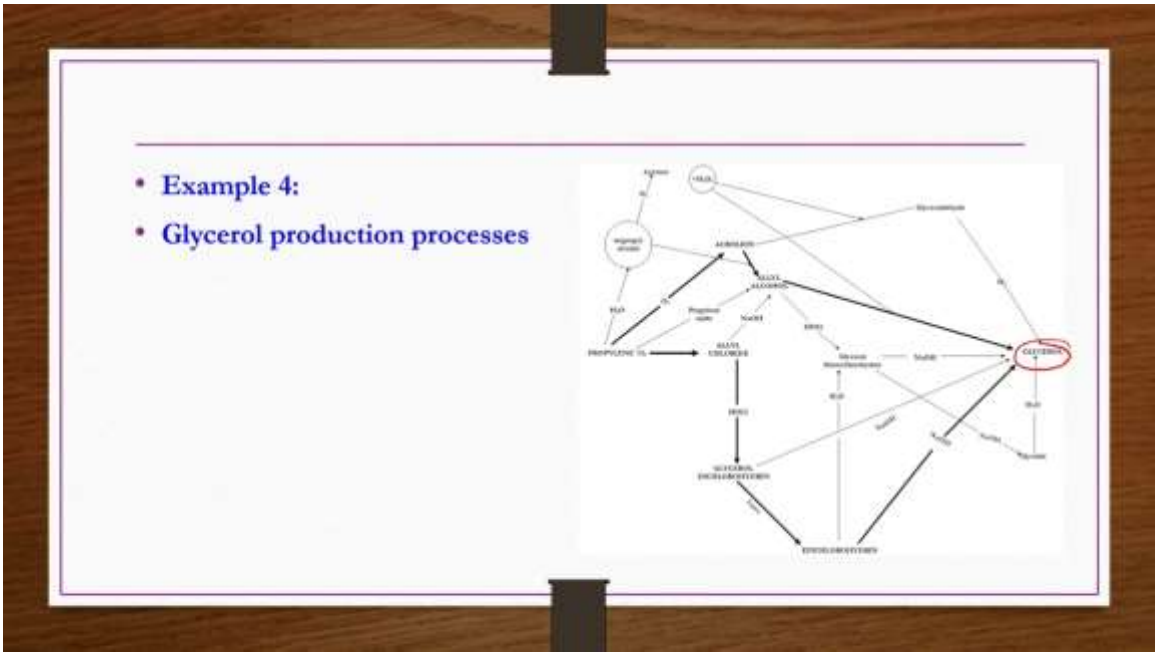


One more example butadiene let us say if you have ethanol, dehydration of ethanol will give the butadiene. Acetaldehyde if you do the decomposition you get 1, 3 butanediol. Dehydration of the same one will give the butadiene.

Then acetylene you have, formaldehyde you have and then hydrogen you have you react them together then you get 1, 4 butanediol. Dehydration of that one will give the butadiene. Then butane dehydrogenation if you do then butadiene you can get. Butane dehydrogenation also if you do then also you can get the butadiene. Butene oxidation you do then also you get the butadiene.

Propane you decompose into the 2 moles of propane you decompose into the ethylene and then butylene as we have seen like this proportion reaction yesterday. Now this butene is there so then again you do the oxidation or deoxidation to get the butadiene. Now you can see so many alternatives are there. Now another alternative is this one.

(Refer Time Slide: 1:11:59)



Likewise, for the glycerol if you see those many number of alternatives are there.

So, you have to choose whichever is more profitable and then more safe and then easy to control during the operation also.

(Refer Time Slide: 1:12:16)

References for the today's lecture are provided here. Outlines of Chemical Technology by Dryden edited and revised by Gopal Rao and Marshall. Then Chemical Process Industries by Austin and Shreve 5th edition. Then Encyclopedia of Chemical Technology by Kirk and Othmer 4th edition. Then Unit Processes in Organic Synthesis by Groggins 5th edition. Thank you.