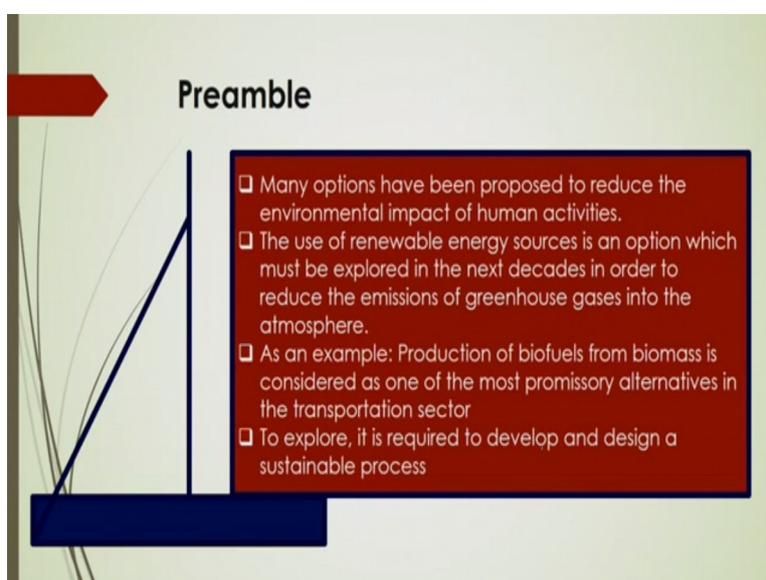


Chemical Process Intensification
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Lecture-9
Strategies in process design

Welcome to massive open online course on Chemical Process Intensification. So under the module 3 Role of Process Intensification in Sustainable Development in this lecture we will discuss something about strategies in process design.

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Preamble

- ❑ Many options have been proposed to reduce the environmental impact of human activities.
- ❑ The use of renewable energy sources is an option which must be explored in the next decades in order to reduce the emissions of greenhouse gases into the atmosphere.
- ❑ As an example: Production of biofuels from biomass is considered as one of the most promissory alternatives in the transportation sector
- ❑ To explore, it is required to develop and design a sustainable process

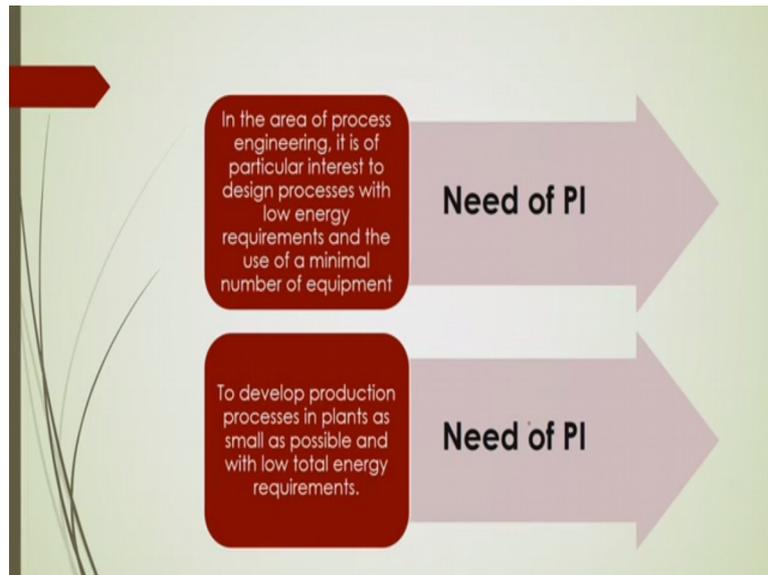
Many options have been proposed to reduce the environmental impact of human activities this is one of the **components** for the process intensification in sustainable development and the use of renewable energy sources is an option which must be explained in the next decades in order to reduce the emissions of the greenhouse gases by industries into the atmosphere.

As an **example**, we can say that whenever we are producing bio fuels from the biomass so in that case it is considered that one of the most promising alternatives in the transportation sector where bio fuels are being used in green technology and this is the process what we can say it is a process intensification in chemical engineering process.

So, productions of biofuels are nowadays considered as an process intensification where the less emission of the carbon can be produced by this bio fuels production. Now to explore it is required to develop and design a sustainable process by which you can produce this bio fuels from the you know that natural sources.

So that is why that you need to have the strategy to actually design the process for the less emission of the green house gaseous, even some other products whatever produced by the process for our daily life products in that case you have to intensify the process in such way that process design to be should be in that direction where you are getting the you know less polluted environment.

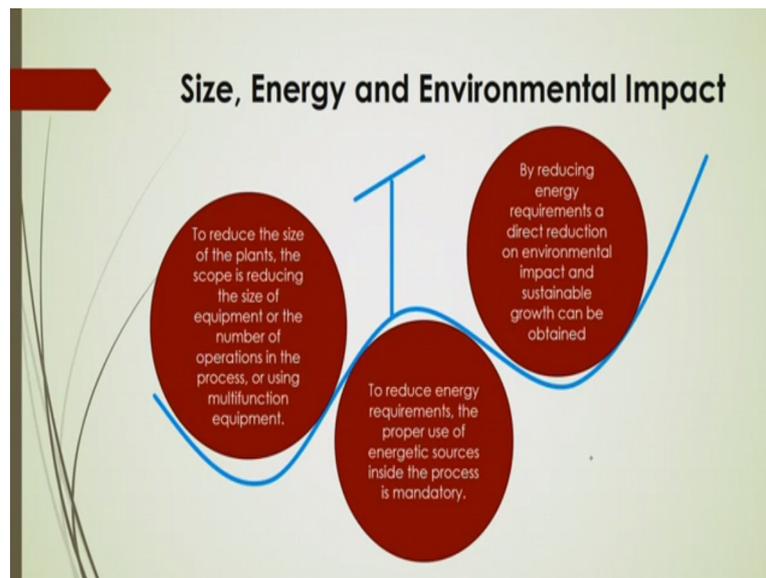
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Now why need of this process intensification that particular process design so in the area of process engineering you know that it is of particular interest to design the process with low energy requirements and the use of you know minimal number of equipment because in that case you will actually consume less energy, if you are producing different products by you know that integration of the process or intensify the process in other way and design it in such way that you are consuming less energy.

So by use of minimal number of why you that energy and equipment you can intensify the process that is why any process in chemical engineering need some process intensification strategy and in that case to develop the production process in plants as well as the possible and with low total energy requirements you need to you know make a policy in such way that your process requirement should be less energy and the equipment will be less in that case.

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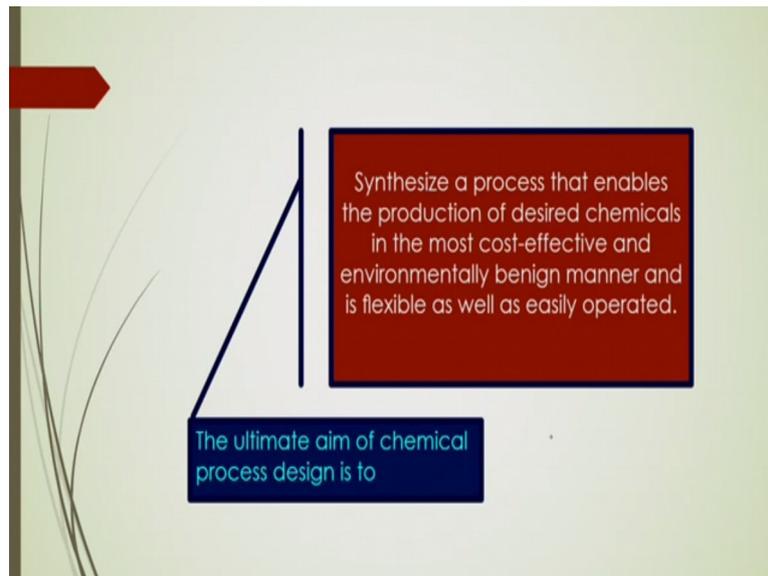
So there are several aspects of that intensification may be in terms of size in terms of energy in terms of environmental impact you can design the process so you can reduce the size of the plants the scope is reducing the size of equipment or the number of you know operations in the process or using multiplication or multifunctional equipment where you can you know that intensifies the process to get the output by consuming less energy and the number of equipment in the particular process.

So, if you integrate the process you can reduce the size of the equipment as well as you know that number of **equipment** there. To reduce the energy requirement also the proper use of you know energetic sources inside the processes is mandatory also. What type of energy are being you are actually going to use that also to be considered whether it is bio fuels or some other energy that you are consuming whether it is the you know that greenery way or not should be considered for the design also.

By reducing energy requirements direct reduction on environmental impact and sustainable growth can be obtained. So, you have to think about that this energy consumption will be economic or not, whether whatever producing a by other processes whether it will keep the processes positive impact in the environment or not, so you have to consider that point the positive impact on the environment for that process design.

So, you have to design the processes or develop the process in such way that consumption, energy consumption will be less whatever energy will be produced that should be produced in a way so that in our case that positive impact of the environment will be there.

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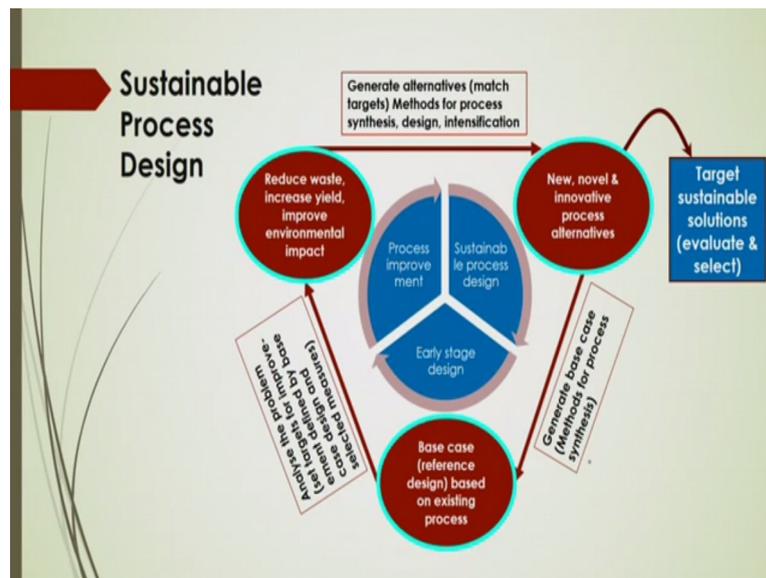
And **also**, you know that the ultimate aim of the chemical process design is to synthesize a process that enables the production of desired chemicals in the most cost effective and you know that environmentally you know that it is called benign manner and is flexible as well as easily operated.

So, in that case you have to synthesis a product by a certain process design, in that case you have to you know that consider whether that product is coming with less hazardous materials or not. Whatever by-products whether it should be you know easily you know separable or not if it is separated how it should be consumed and where it can be you know reused that should be also considered in that case and for overall you have to calculate the how much cost actually factor will be they are in that particular design.

So if you design that process by considering the size of the **equipment**, number of the **equipment** when you know that synthesis of the chemicals whatever solvents as a reactant should be used or any physical operation what are the you know material to be used that should be considered **there**.

So that is why you have to design the process in such way that should enable the production of desired chemicals in the most cost effective and the environmentally friendly and also it should be flexible as well as easily operated. **So**, these are the main aim of the chemical process design.

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Now, for that process it should be sustainable of course so get the sustainable process design you have to you know that remember different aspects of that things. Sometimes you have to know that process improvement several components for that like sustainable process design, early stage designs, you have to consider that whatever design earlier is they have used so that should be considered because from that onward you can improve also otherwise newly process can be developed or designed there.

So, based on the earlier process you can also design or you can intensify the process like you know that everybody knows that there is a two-phase operation, gas-liquid operations there, you know that development or you can you know producing the bubbles in cash liquid system in a continuous liquid phase to a separate the gaseous stream into a liquid stream.

Now, later on whatever it can be intensified by producing the process or producing or developing the process in such way that if you can reduce the size of the bubble you can get more interfacial area through which that mass transfer would be more, so this is the one way to you know that get the intensification of the process.

So, in that case increasing the surface area reducing the size of the bubbles and also if you do it in a suppose certain you know process device then in that case development of the process design also other way to you know that intensify the process. So, you have to consider the earlier stage and from that you can intensify the process, otherwise to get the new process you have to consider other several factors like energy consumption whether it should be eco-

friendly or not, whether it will be environmentally positive impact or not, that should be considered.

So, in all these things should be considered for the sustainable design. So, you have to then consider that 3 components here early stage design after that sustainable process design to be considered and then you have to consider that whatever it will process improvement or not so all these things the cyclic way you have to consider.

Now based on these thick components you have to you know that consider the base reference design based on the existing you know that process, so from who is you can you know that analyze the problem where that earlier stage design is there because of which you are getting less yield.

So, based on that you have to set target in such way that you can intensify the process to get the more mass transfer, more heat transfer, more you know that you can say transport processes there. Whether it is physical or chemical processes or not, so based on this you can improve that you know process design and based on which you can apply that things, you can get the reduce waste even increased yield and also improve environmental impact there.

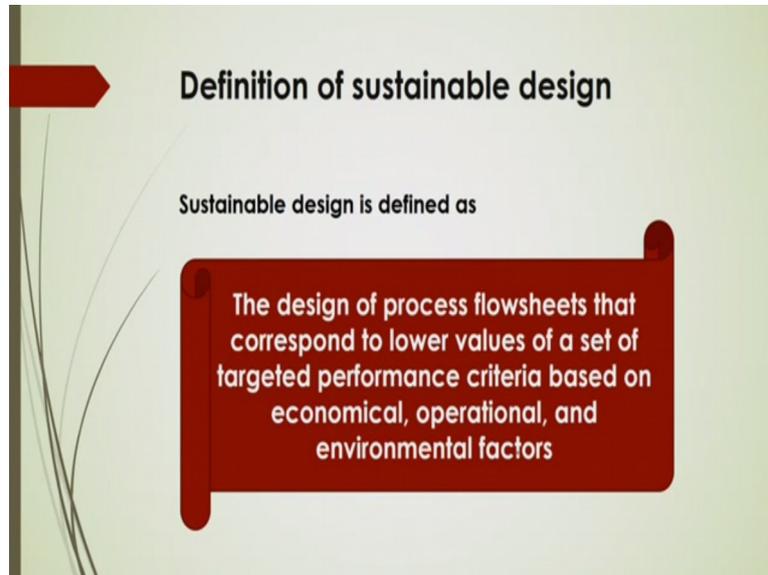
So, after that you can generate the alternatives that should be matched with the targets and methods for the process synthesis designed and intensification to be actually you know that accounted for that particular sustainable design. And after that if you are thinking that you are producing the process or you can derive the process for that particular synthesis and designing that equipment in such way that for that particular process synthesis, for that process intensification you have to think another way that is alternative way how to do this.

For that you have to think about the new process novel innovative way to do that you know that synthesis. So parallelly you have to think about that not only that intensify the process of existing you know process you have to think parallelly what I can do for the new improvement of that process and new development of the process or new way to actually synthesis the materials based on the available materials there.

So that is why new noble and innovative process alternatives should be also considered for the sustainable development. And in that case best case should be generated and also methods for the process synthesis should be considered for that process alternatives and ultimately your target should be the sustainable solution for that particular process and also you have to evaluate whether it should be sustainable or not.

So **finally**, at a **different level** you have to do this process design and for the final recommendation you have to then analyze or you have to assist the process whether it should be feasible for the sustainable development or not.

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Now, what is that actually definition of that sustainable design. First of **all**, you have to know that what are the different components for that sustainable design to be considered so based on that the design of the process flow sheets that should be considered where it will correspond to **a lower value of a set** of targeted performance that should be the criteria and based on that criteria economical operational and environmental factors to be considered for that sustainable design.

So that is why the sustainable design is to be defined as the design of a process flowsheets that correspond to lower values of a set of targeted for performance criteria based on the economical, operational and environmental factors so this the definition for that sustainable design

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Role of Process Synthesis

- The role of process synthesis in finding the early stage design and/or the more sustainable design is to generate the feasible process alternatives.
- The generation of alternatives can be done in various ways, for example:

Two circles containing the following items:

- trial and error,
- rule-based heuristics,
- process integration (mass and energy),
- process optimization,
- process integration,
- and many more.

Now, what are the role for that process synthesis to give you the sustainable design. **So** in that case whatever synthesis, process synthesis actually you know that you are considered, there should be a certain role for that. **So**, in that case role of the process synthesis to find the early stage design and the more sustainable design to generate the feasible process alternatives.

And the generation of the alternatives can be done in various ways, for example, it is given like you have to consider the trial and error methods, **rule-based** methods you know heuristics process and process integration generally for mass and you know that energy conservation that you have to consider for that process integration and also process optimization it is very important.

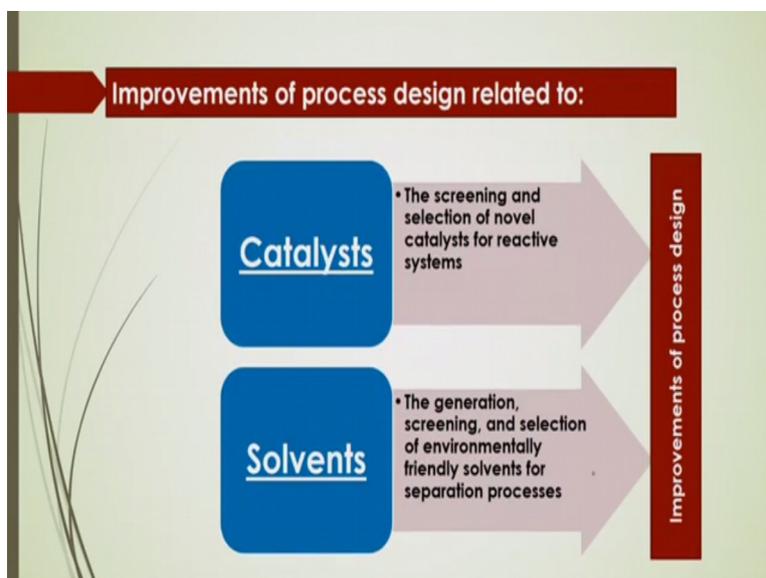
Whether this process it is developed that should be optimized based on the different operating variables and the process integration should be considered based on that operating variables whether that variables can be reduced for that process integration based on the concept of you know that for mass and energy conservation criteria.

So, and also other many factors you have to consider like your policy, like you that materials available whether that materials should be you know that green materials or not whether it should be hazardous or not whether it should be you know environmentally acceptable in range or not that everything should be considered for that process synthesis.

So, the rule of the process synthesis is to find out the early stage design and one more sustainable design to generate the feasible process alternatives for the process intensification

and different ways are that here trial and error, **rule-based** heuristics, and process integration based on mass and energy balance, process optimization and more.

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Now how to improve that process design and it is related to different criteria different you know materials if an you that operating variables, even other you know renewable resources that will impact on that you know improvement of that process designed. **So**, process design that related to the materials like catalyst solvents. Catalysts means the screening and the selection of the novel catalyst for the reactive system to be considered that you have to synthesis the novel catalyst for a particular reaction.

So that is why the catalyst whatever it is synthesized whether it is the environmentally giving the positive impact or not so for that you have to consider and based on that you have to improve the process design. Solvents whatever it is being actually used for that process design whether **these solvents** will be environmentally friendly solvents or not and also that solvents whatever it is to be used simply like that for extraction process after extraction of that organic compounds that should be separated.

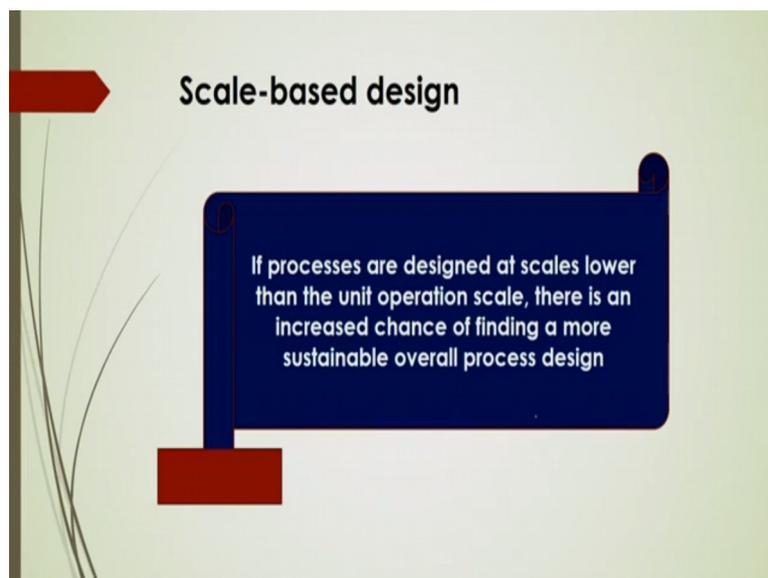
Now, **these solvents** whether it should be easily separated or not. **So**, based on that separation criteria you have to develop that solvents or you have to use the solvents for the particular process and accordingly your process should be designed. And other like materials, the design of the new materials to be considered here and whether it should be novel or innovative and whether it should be giving the novel innovative operations based on that

materials or not and whenever you **leave** that materials that should be giving the combined reaction and also separation and reaction separation systems altogether or not.

Similarly, energy also to be considered through use of the process integration concepts to generate more sustainable process alternatives with respect to reduced waste and environmental impact so you have to design the process in such way that where less energy will be consumed and that energy whatever it is produced that can be from the waste material or some other systems in the process integration system.

What is that process integration system? Sometimes wet bar heat will be wasted that heat should be reused for other processes so that is why process integration will give you the intensification of the process where less energy can be consumed by utilizing the wasted energy in a particular process. **So**, energy is one important **criterion** which will impact or which will **affect** on the sustainable process design.

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Now other thing is that **scale-based** design if the processes are designed at a **scale** lower than the unit operation scale, there is an increased chance of finding or more sustainable overall process design. So, in this case sometimes you will see for the chemical engineering process like reaction engineering.

Now a days some process equipment are being designed in such way that it is a scale should be very lower in size like you know that micro reactors, micro channel reactors, micro heat exchanger, even you know that microchip heat exchanger, you know micro channel based heat exchangers.

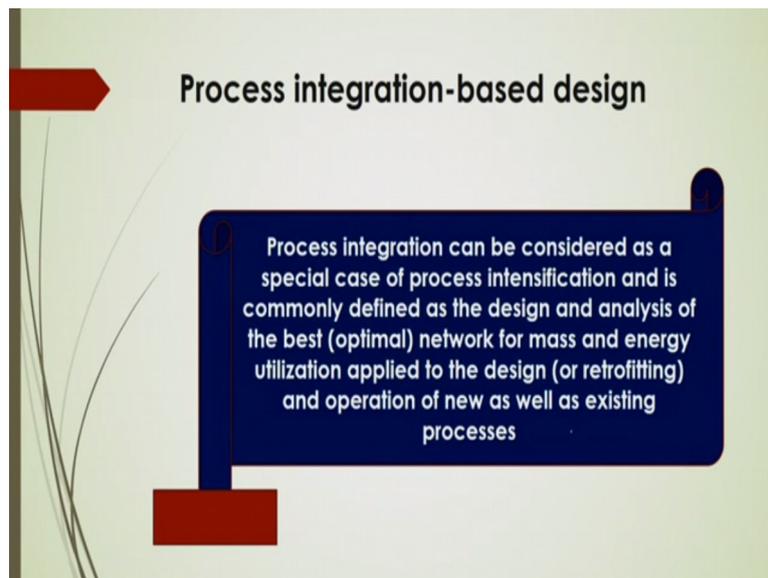
So those you know that devices are being used now a days where that scale is the main important factor. You are just designing the process equipment in such way that you are just reducing the size of the equipment, reducing the size of provision or mechanical devices whatever is being used they are.

So, in that case for that particular unit operation that is scale, in that particular scale that unit operation should be intensified that means process, chemical process in the reaction, suppose the first reactions the channel based where you can get the more interfacial area. So, in that case the scale should be reduced like I told you, I told that the micro bubble or nano bubble to be produced to get the more interfacial area which is being used in you know that waste water treatment.

Which is being used for you know that material processing which is being used now a days for medical science like you know that you for ultrasonography system they are also, they are using this micro bubble system, that is a scale you know micron size bubbles are being used even, gene therapy, even you know that drug delivery that micro bubbles are being used for that.

So, the you are designing the system in such way that either your fluid system or fluid particles are actually reducing its size or your equipment that is being reduced for that particular chemical engineering process or not. So, if the **processes** are designed at a **scale** lower than the unit operation scales there is an increased chance of finding a more sustainable overall process, like in that case you can get the more mass transfer, more heat transfer and other chemical engineering operation yield.

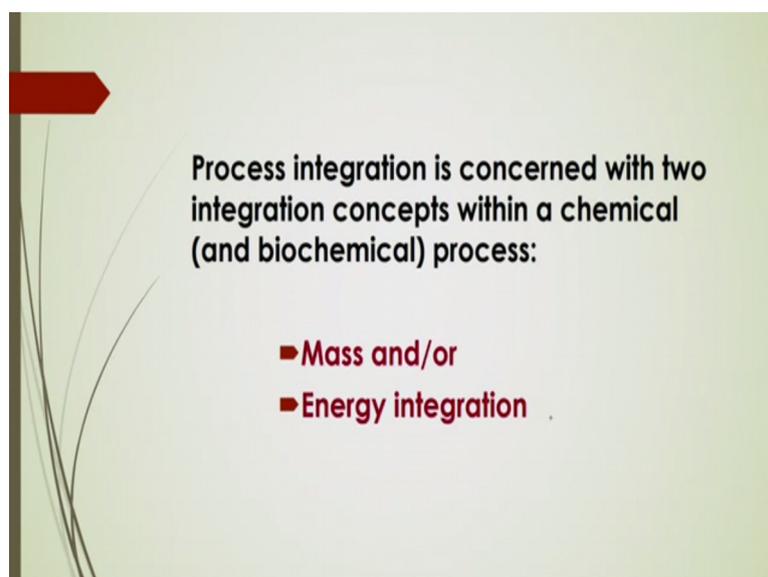
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Now process **integration-based** design, in that case it can be considered as a special case of process intensification and is commonly defined as the design and analysis of the best or optimal network for mass and energy utilization that is applied to the design or you can say that retrofitting and operation of new as well as existing processes.

So, you have to consider the processing integration in such way that your special case for that you know that design and analysis to be in such way that mass and energy utilization should be less and it should be applied in such way that that you are getting more yield by giving the less energy and also it should be eco-friendly.

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Process integration is concerned with two integration concepts within a chemical process. Any chemically engineering process you will see whenever you are considering intensification you have to go through **these two words** like mass and energy. **So**, you can get the intensification of that chemically engineering process by conserving this mass and by conserving that energy.

Now, sometimes for conservation you have to use the less mass or you have to intensify the mass transfer like the transfer of the material from one phase **to another** phase there what will be the mass transfer, to get the intensification of that mass transfer, you have to increase the interfacial area of the phases through which that mass transfer will happen.

Now, if you suppose do that you know that absorption of the gaseous components to the liquid medium, so you have to produce the surface area between the gas and liquid through which that you know that a mass transfer will happen. Now, earlier stage you will see that there is weighted column in chemical engineering process in that case through the center of the column gas is supplied whereas adjust into the wall, the liquid will be falling down or is being falling down as a thin liquid.

So, in that case there will be contact between gas and liquid so through which there will be a mass transfer. Now in that case it is seen that for that overall volume of that gas liquid mixer the energy will be high whereas you are getting less contact area. Now, it is for the process intensification this is being modified like peoples are thinking different way to get to the interfacial area between gas and liquid.

So, for that what you have to do or peoples are doing, they are designing the process with that if you can produce bubbles of gas in a liquid medium then you can get the interfacial area so that you can get more you know that mass transfer between that surface. **So**, if you are producing bigger bubbles, you can get one's interfacial area, if you break that bigger bubbles into a **finer bubble** you can get more interfacial area than earlier.

So, in that case intensification is going on just based on the increase in the interfacial area. Now, to increase that interfacial area what is the **an** actually energy is being used for that, now energy consumption or energy dissipation that is coming you know that air or gas to be supplied to the liquid medium by compressor.

Now, what will be the energy consumed by the compressor that should be considered, so that is why the energy consumption should be less and such with that whenever you are producing

the gas bubble to get more interfacial area you have to think for the design of that you know the process to produce that bubble in such with that you are using less energy.

So, the concept of processing intensification that with that whatever energy is consumed for that you know that a producing that bubbles and that bubbles will give you the mass transfer and after that that energy whatever it is dissipated that energy may be used for other purposes now what is to consider for that reuse of energy.

Now, if we consider that suppose fluidized bed operation, in your case simple example, however, suppose you know that coffee bean, now how to roast that you know coffee bean, green coffee bean to be roasted after that it will be made as a what is that a dust of that coffee bean than you are getting the serve of your what is that a coffee, now to make that a brown coffee bean or roasted coffee bean you have to use some fluidization process.

Now, in that fluidization that coffee bean fluidized in the air medium, hot air medium, now hot air is to be supplied through compressor and through the heat extender and after that coffee bean will be roasted. Now this hot air if you are not using further that energy should be wastage, now if you can use that wastage hot air for other purposes then your integration process will be there and you can utilize that wastage energy and you can intensify the process based on the less energy consumption.

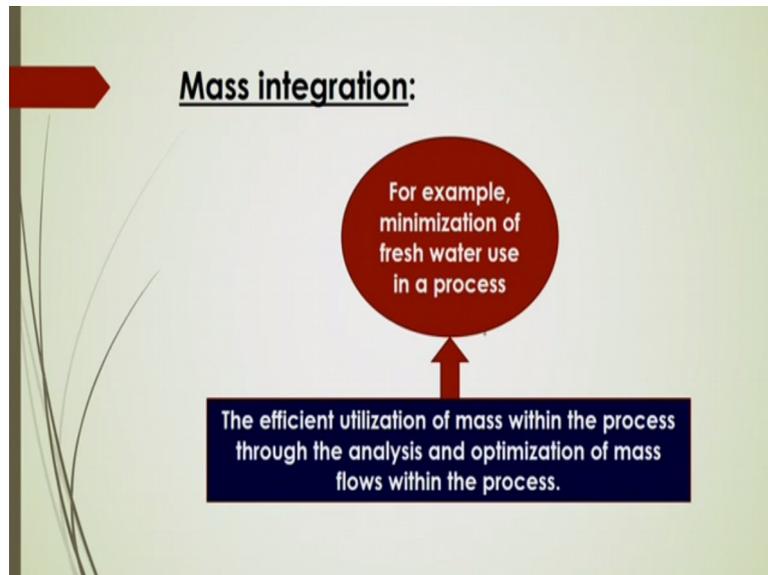
So this is the way, so you can use that hot air for other you know chemical engineering process where the liquid should be you know that heated up at certain temperature so that hot air energy, hot air if you supplied for that through the heat exchanger, another heat exchanger for the heating of that liquid medium for that reaction or other separation processes in that case you can reuse this energy.

So, one compressor and through that one of that heat **exchangers** whatever is produced there whatever supplied there and use two or three processes there, so that is why some other process like that if your reaction is suppose exothermic reaction so heat is you know that will be produced there based in that particular reaction.

So exothermic reaction whatever heat is coming out if you can use that heat for other you know that processes than you will be benefited or the process design should be in such with that integration of that two processes will be done you can get advantage of using that energy and getting the less energy consumption by integrating that process and your process will be

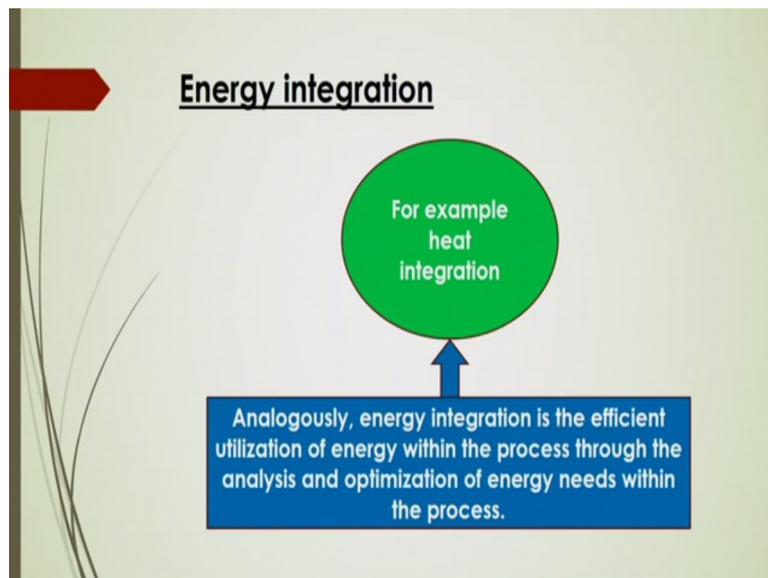
intensified. So that is why the process integration is concerned with two integration concepts within a chemical or biochemical **process** like mass and energy integration

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What is the mass integration? For example, I have already told that minimizing of the fresh water use in a process like the efficient utilization of mass within the process through the analysis and optimization of the mass flow within the process. **So**, you have to utilize of the mass within the process based on your less consumption of the mass or suppose solvent you are using, how to use that less solvent or amount of solvent and to get the maximum separation of the other organic compound. So that is why mass conservation mass utilization mass optimization within the process to be considered for that particular mass integration process.

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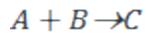
Energy integration like heat integration whatever heat is coming out in a particular process that can be reused for other processes that is why analogously to that mass energy integration is the efficient utilization of the energy within the processes through the analyzes and optimization of the energy that needs with in the process. Like example, that heat integration already we have given the example for that you know that fluidization after that whatever is heat is wastage that should be reused for other chemical engineering processes.

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What is the role of chemist for process design?

- To cope, a process design chemist will alter conditions to slow the reaction down.
$$A + B \rightarrow R$$
- Running at lower concentrations (i.e., more solvent) or operating semi-batch—feeding B in slowly over many minutes or hours so that the system can cope with the heat release.
- If a chemical reaction that would naturally take place in a few seconds is slowed down to take 12 hours or more, it is clearly inefficient

Now, what is the role of that chemist for process design? You will see that in that case suppose a process is being designed by the chemist where the reaction like A plus B it will give you the product R.



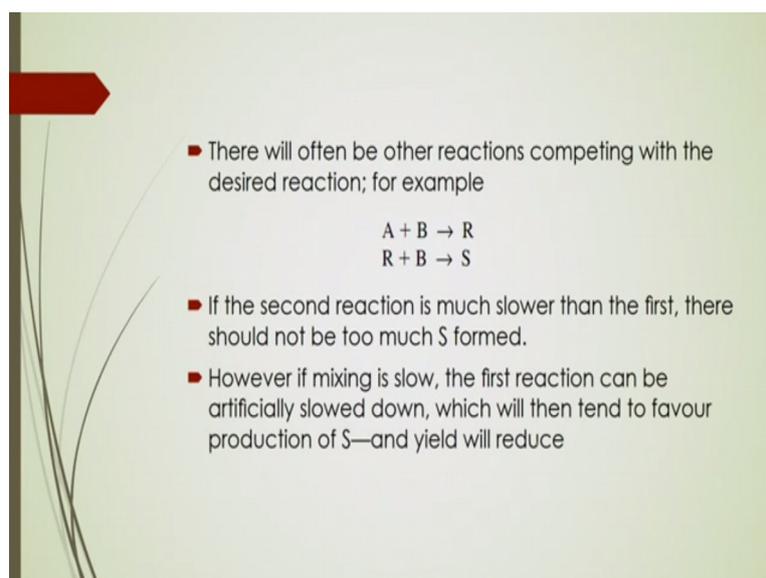
So in that case you have to consider the reactant concentration, now if you are using the lower concentration of any suppose reactant ok.

Now, in that case to lowering the concentration you have to use more solvent or operating semi-batch process where feeding of any reactant like here B and slowly over many minutes of hours you know that so that the system can cope with the heat release. So, if a chemical reaction that would you know naturally take place in a few second and it will be slowed down to take a you know 12 hours or more it is clearly inefficient it will be called.

So that is why the role of the chemist for the process design is very important for the consideration of the reactant what type of solvent to be use, whether the concentration will be enough or not, whether it is the batch process or continuous process or how what would be the mechanism of the feeding of the B that whether it will be slowly manner or the fast that should also be considered.

Because that will give you the residence time of reactant of particular reactor and residence time of the reactor will give you the process yield or reaction yield there. So that is why the chemist always consider this a reaction mechanism as well as the what is that the concentration of the reactant to be used and also how it would be supplied whether semi-batch or continuous way.

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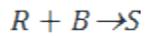
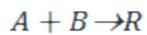


There will often be other reactions competing with the desired reaction; for example

$$A + B \rightarrow R$$
$$R + B \rightarrow S$$

- If the second reaction is much slower than the first, there should not be too much S formed.
- However if mixing is slow, the first reaction can be artificially slowed down, which will then tend to favour production of S—and yield will reduce

There will be often other reactions like competing with the desired reactions for example A plus B will give you R, R plus B will give you S.



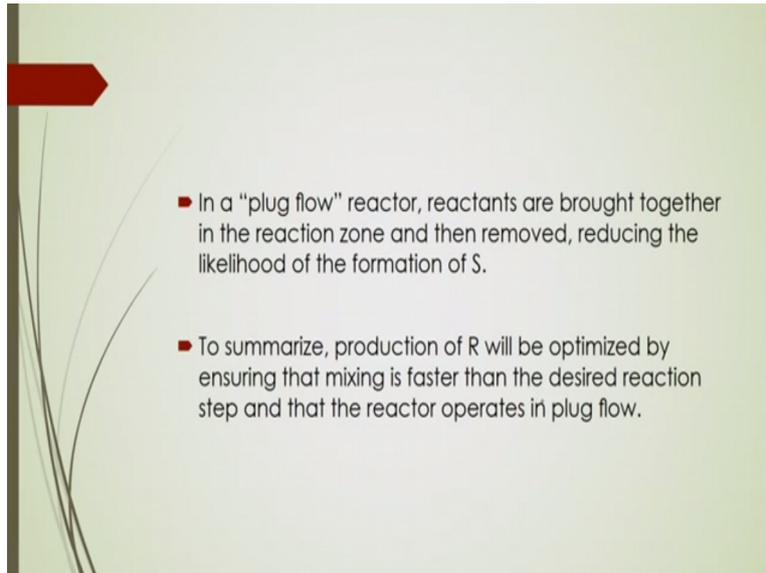
Now if the second reaction in this case is much slower than the first there should be too much S formed and it should not be actually advisable or it should not be you know considered or it should not be desirable.

So **however**, if mixing is slow in that case the first reaction can be artificially slowed down which will then tend to favour production of S that is here the final product and yield will be reduced accordingly. **So**, in that case mixing is one important **criterion**, you have to slow down that mixing for particular you know that final product of S to get more yield in that case.

So, first reaction can be you know that easily slowed down whereas for slow reaction what will happen, you cannot actually control that mixing phenomena so for slow reactions you have to intensify the mixing inside the reactor. So, in this case if you are increasing the mixing so only the slow reaction or you can say that where the physical separation is very slow, mass transfer will be very slow or mass transfer coefficient will be very low, so in that case you have to consider the you know the first mixing of the slow reaction.

Whereas for first reaction A will give you the directly here S not intermediate product like R so for that case since you in this case the mixing is slow the first reaction that is A plus B is equal to R here so can be artificially slowed down to give you the final product for S and in that case your yield may be sometimes you know that reduce based on that you know that slowing of mixing. So, in that case you have to control the mixing characteristics inside the reactor to get the more residence time there.

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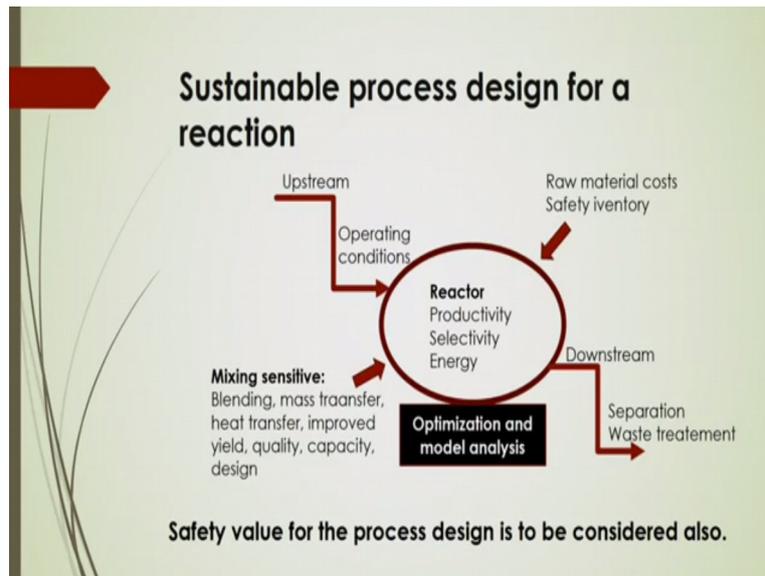


Now in a plug flow reactor, reactants are brought together in the reaction zone and then removed using the likelihood of the affirmation of S. So if you are using starting reactants you are getting that mixing characteristics that is you know that arbitrary directions of the fluid element that whatever you know substrate you were using or reactants you were using so in that case back mixing may happen so due to that back mixing there will be yield of reactions will be low where else in the plug flow there will be no signs of the back mixing of the reactants.

So, it is called plug flow phenomena. So, in the plug flow reactors, reactants are you know that coming to each other and in a particular zone there will be a reaction and you can reduce the you know the final product of S based on that plug flow phenomena, so to summarize production of R will be optimized by ensuring that mixing weather it is fast or desired reaction step and that the reactor operates in plug flow phenomena.

So, in that case process intensification may get based on this plug flow phenomena, because of this plug flow phenomena will give you better yield, now a days that micro channel-based reactors are coming. So, what that micro channel-based reactors are, now a days you know that recommending for the first reactions to get the better yield.

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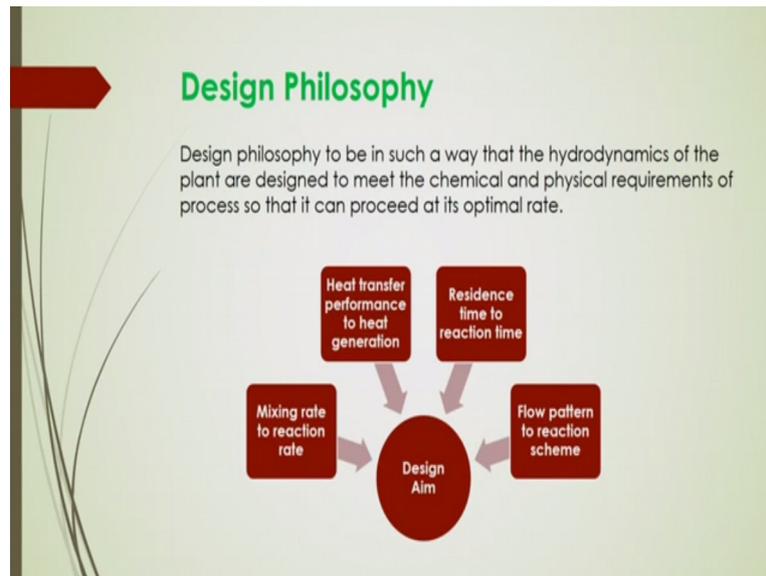
Now what will be the sustainable process design for a particular reaction, now if you reaction to be done in a reactor were you can assess the productivity, you can assess the selectivity based on the energy supplied. Now, you have to optimize that reaction yield or product based on that energy and also that other you know that operating variables. Now, what are the upstream and what will be the operating conditions for the downstream what will be the, you know separation or waste management treatment all the process to be there.

So in that case what will be the raw material to be used what will be the cost of that raw materials that also to be considered whether it should be safety inventory or not and also whether it should be mixing sensitive or not whether it should be properly blending or not whether mass transfer has happened properly or not, whether hart transfer has happened properly or not how can you improve the yield based that based on the mixing quality and also you know that capacity of that design that also to be considered there.

So for the overall reactions to get the sustainable process design you have to consider that upstream along with that operating conditions and downstream and also you have to consider that separation mechanism and also how to that you know manage that wastage material by that you know that output of that reaction and in the reactor you have to model you have to optimize the process of productivity based on that operating conditions and also raw materials whatever will be used what will be the price you have to consider for that.

So, for the sustainable process of design this outlined of the reactor with the optimization and model analysis to be **considered**. **So**, safety value also to be **parallelly** considered for the process design for especially for this reaction system.

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Now, what are the design philosophy in that case now if you consider that hydro dynamics of the plant and if you considered based on that hydro dynamics how to design the chemical or you know that physical process how to design so all physical operations or you can say chemical operations in the chemical engineering process you can see everything that depends on the Hydrodynamics.

So, you have to know the hydrodynamics first any reactor whatever suppose fluid is used in a reactor suppose there is a chemical reaction is going on, now reactions to you know occur this reaction or to perform this reaction what you have to do you have to supply some reactant through some you know that inlet and there will be outlet.

So there inside the reactor there will be a you know movement of the fluid, now you have to know that flow pattern of the movement of the fluid whether it is the back mixing whether it is plug flow phenomena or whether it is ideal reactor or whether it is non-ideal reactor or what extent of non-ideal it will be there that can be you know that asses by the mixing characteristics like the one you know parameter in the mixing what is the intensity of the mixing that you can assess by the residence time distribution, like excel dispersion model to be fit there you know they are that **Peclet** number that to be considered there one by **Peclet** number it is generally defined for the dispersion number.

Now, if you have the more dispersion number you can say that there will be more mixing inside that so based on that dispersion number you have to asses whether this degree of mixing is enough or not it will give you that ideal or nonideality of that reactor. So the flow

pattern you know that fluid mixer how it will be mixed and also fluid element if you suppose that particles are being used what will be the you know that flow pattern of that particles, what will be the distribution of the particle inside the reactor that should be considered all things are considered to be the hydrodynamics.

So, based on that hydrodynamics your reaction yield process will to be considered or assessed. So based on that hydrodynamics you have to design the reactor and were you can get the reaction yield based on that design so you have to think that design of that process in intensified way so that you can get more uniform distribution of the solid particles more finer particles will be used there you can produce more particles, Particles that are produced there you can use soft particles of that phases and also contact between the phases can be increased by that you know that mixing phenomena or other way and distribution of the heat also to be considered.

So, you have to consider all this heat transfer phenomena mass transfer phenomena like design aspect heat transfer coefficient mass transfer all those **parameters** should be considered for the design of this you know that process. So that is why hydrodynamics is one of the important factor where this to be considered for the process intensification for sustainable **design.**

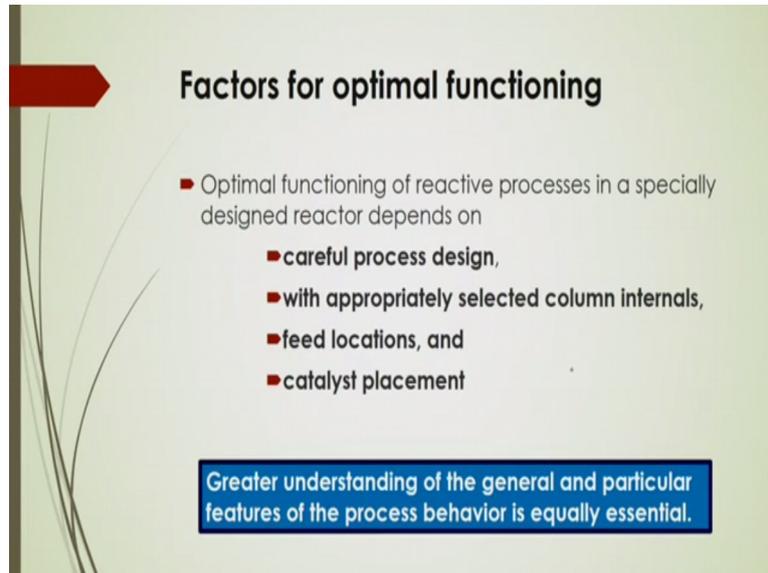
So that is why the design aim is to mixing rate to reaction rate to be considered, heat transferred performance to heat generation, residence time distribution of course that mixing phenomena will give you the residence time distribution how long that fluid particles will residing inside the reactor. For the first reaction it maybe you know that low but for the physical operations where more time is required in that case you know that residence time to be considered based on that mixing phenomena and other design, sometimes you have to use some provisions in a reactor so that back mixing will be less.

So that is why in that direction you have to design the process, now flow pattern to a reaction scheme that is very important you know that for ideal reactor for non-ideal reactor flow pattern is the very important if you are getting the plug flow there are different types of flow pattern you know slack flow, plug flow even you know that bubbly flow, even you know that pneumatic bubbly flow, even sometimes you will get that mist flow, spray flow.

So, all those things are different types of flow pattern that different flow patterns will give you the different consumption of energy based on which you can get the reaction yield or

process yield based on that flow pattern. So, you have to consider this flow pattern so flow pattern residence time distribution heat transfer phenomena mass transfer phenomena or those things are coming as a hydrodynamics part so you have to consider all this hydrodynamics part for your process design.

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Factors for optimal functioning

- Optimal functioning of reactive processes in a specially designed reactor depends on
 - careful process design,
 - with appropriately selected column internals,
 - feed locations, and
 - catalyst placement

Greater understanding of the general and particular features of the process behavior is equally essential.

Factors for optimal functioning. Now optimal functioning of the reactive process that you have to consider for that reactor design that will depend on careful process design with appropriately selected column internals, feed location and catalyst placement, very interesting that whenever you are designing any reactor that you have to consider that process design in such way that if any internals are required or not because your process intensification will be based on mixing of that reactants.

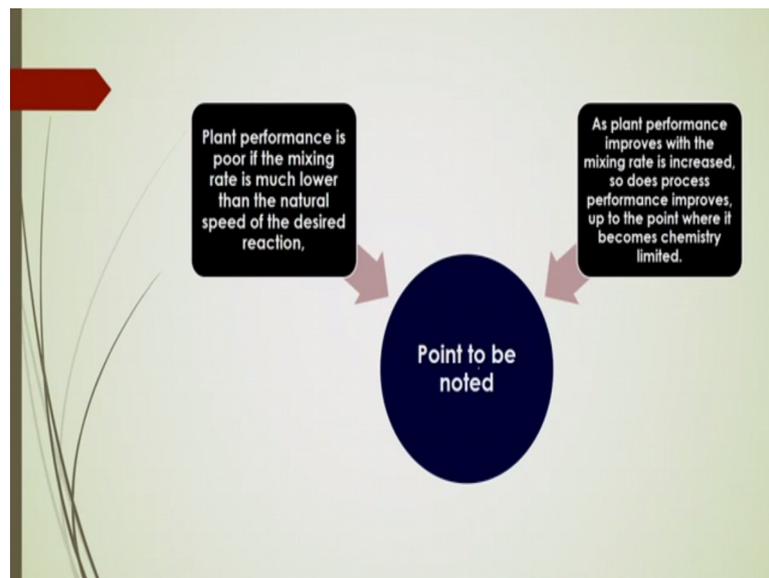
Now if you are using any internals for the mixings to intense the to get the more degree of mixing you have to use some you know that baffles or some other provision so that the liquid will go through the you know path where get more obstructions and also fluid particles will be getting more you know that agitated and so that you can get more mix of that fluid phase there.

So that is why you have to select the appropriate internals for that, even sometimes you know that for heat transfer also to get the more uniform heat transfer you have to design the system in such way that whether it is the channel-based heat exchanger or some other way to get the more heat transfer phenomena.

Also feed locations in a certain you know that suppose distillation column, extractive distillation so in that case extraction as well as distillation both will be happening. So, in a particular where that feed location should be you know design, you have to give proper design of that of that feed location based on which you will see that performance of the process will be changing. **So**, feed locations are important factor where you have to consider.

Catalyst placement also you have to supply the catalyst either in continuous way or batch wise way. Now, catalyst you have to place in a particular way that it is in the distributed location or in the top location that you have to decide and based on which you have to design your process equipment. So greater understanding of the general and particular feature of the process behavior is required to know for that particular optimal functioning process design.

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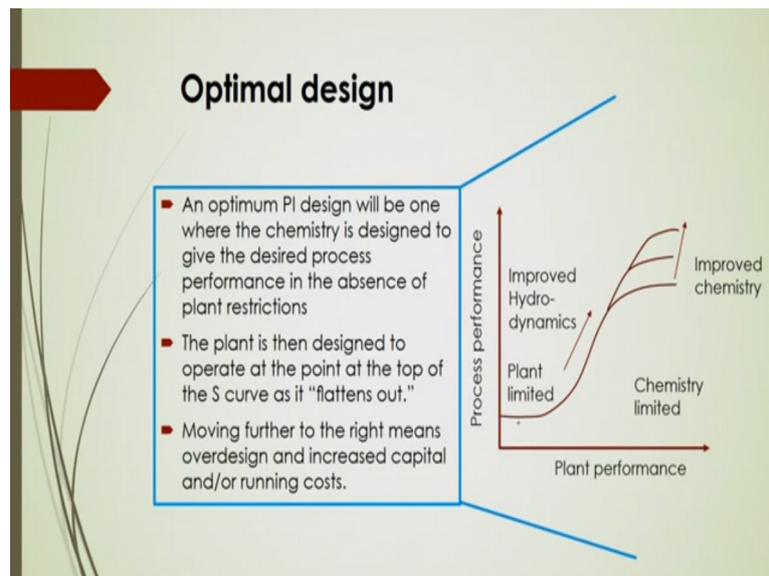


Now, in that case point to be noted that plant performance is poor if the mixing rate is much lower than the natural speed of the desired reaction also as plant performance improves with the mixing rate that will be increased so does process performance improves up to the point where it becomes chemistry related.

So in that case you have to consider the mixing rate whether it is the lower or faster, whether it is the natural way of getting that speed of desired reaction or not and you can improve that you know that performance of the plant by this mixing rate, if you increase the mixing rate performance may improve sometimes may also may not be improved because you know that some mixing it will give you the less yield.

So, in a particular **case** that is case wise that mixing will improve the performance of the plant. **So**, all these things actually you know depends on the chemistry, what are the different solvents, what type of you know that reactions will be going on whether it will take more residence time or not. **So**, based on that chemistry part so all this you know that plant performance will be depending upon.

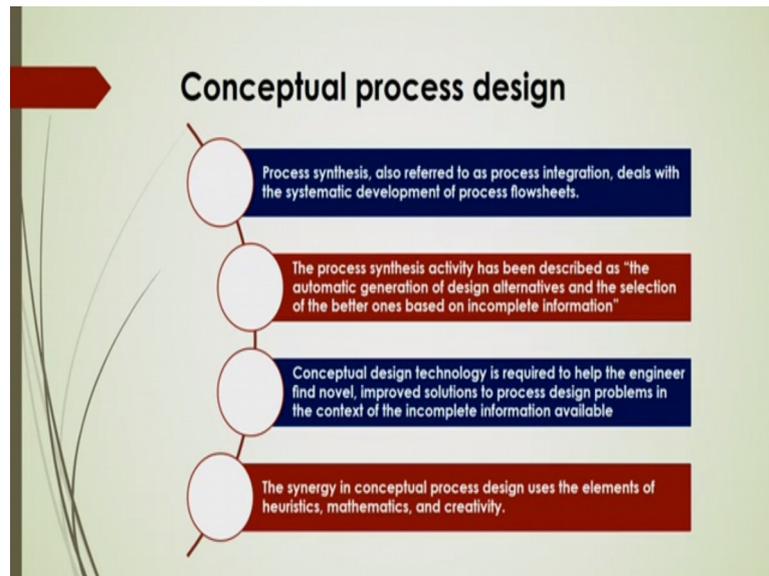
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Now optimal design you know that for that particular design of that process plant that plant performance will be you know depending on that plant size, you know that plant policy you know improved hydrodynamics phenomena that I have already discussed, even what is the chemistry behind that what are the different you know that greener chemistry or you know that greener chemicals will be used materials to be used, solvent should be used, catalyst should be used that should be considered and also you know that improve chemistry like you have to synthesis the materials in such way that less hazardous materials should be reduced.

So, that is why plant performance and process performance both are interrelated in that case process performance would be directly related to that plant performance based on this hydrodynamics and plant policy chemistry and other operating variables. So that is why the plant is to be designed to operate at a point at the top of the S curve here as shown in here figure as because here at this improve chemistry where the S curve will be flattens so in that particular location you have to consider to get the optimal design.

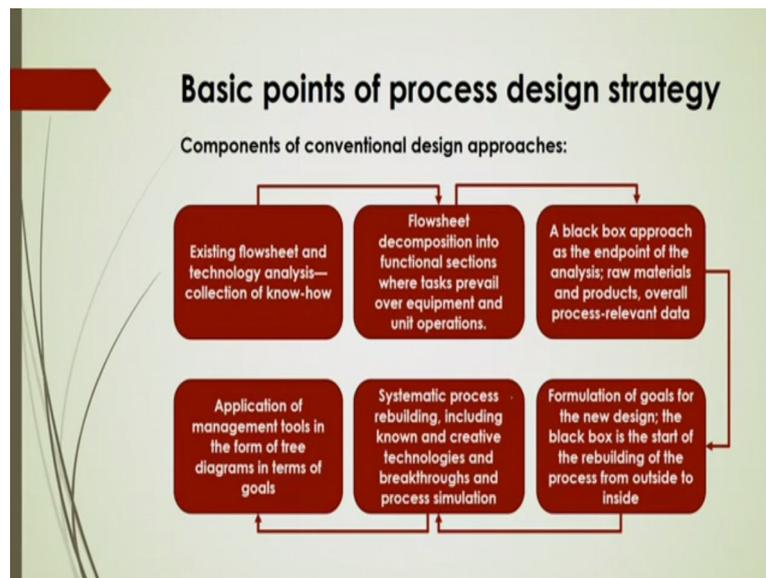
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Now for that conceptual process design you have to consider that process integration and which will be dealing with the systematic development of the process flow sheets, process synthesis activity and also the automatic generation of the design alternatives and the selection of the better you know that once based on the incomplete information also.

Also, that conceptual design technology is required to help the engineer to find out the novel and improved solution to process design problems in a sustainable way in the contest of the incomplete information whatever is coming from the earlier stage and also available resources. The synergy is conceptual process design that will use the elements of the you know heuristic mathematics and the creativity of that so all these things should be considered whenever you are going to design a particular sustainable process.

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Now basic points a process design strategy what are the strategy for that. Now components for that conventional design should be considered here for that strategy in that process flowsheet should be considered. Now what are the adjusting process flowsheet and the technology that should be you know that considered for the analyze of that you know intensification way a process design.

And you have to collect all those things process you know information and you have to make the process flow sheet based on that you know how of that you know information of that you know adjusting flowsheet and then you have to decompose that flowsheet into a functional you know sections and also whenever you are going to you know that sectionized that functional task that you have to you know consider that equipment size and also particular process knowhow of that you know operations.

A black box approach as the you know that n point of the analysis that also to be you know that considered and this is the main strategy for this you know process design in that case raw materials, products overall process relevant data should be you know that considered for your design otherwise you not get.

You not be able to assess the optimal design if you do not know that you know raw materials, cost of that raw materials and also products, what about the products and will be the separation criteria, what will be the different physical properties or the process yield what is coming that should be considered and also overall process relevant data also sometimes you

know that mass transfer coefficient, heat transfer coefficient, reaction kinetics all those things to be considered.

So, this is the strategy that to find out the process design optimal process design for the sustainable development. Now, next what you have to do that after getting this process relevant data for that black box formation you have to formulate the goals for the new design and the black box is the start of the rebuilding of the process that from the outside to inside.

So that is why all this process design data to be considered that to formulate the new design and after that you know systematic process rebuilding and you know that including known and creative technologies and also what will be the breakthroughs and process simulations that should be considered for your you know that systematic way of process design.

Now simulation is very important whenever you are designing that process what will be the outcome expected that you can predict based on your you know model development after the simulation means what is that based on that model you can expect the what is the trained of that output after design that you have to consider that is the strategy here to you know that consider the model and what will be the prediction trend of that particular process output will come based on this simulation.

And then application of the management tolls in the form of tree diagram in terms of goals of course, you know that whatever goals you are expecting based on this simulation then you have to target that goal. Suppose within a certain time period you expect this you know that output this you know amount of output is required based on the operating conditions, based on the you know the process relevant data, based on your equipment design.

Now if you are targeting the goal of this output based on this simulation data then you have to fixed management tools in the form of tree diagrams so that for **these particular operating conditions** you can get this output, for this particular you know that step you can consider these things for this control of things of this input you can get this output. **So**, this type of things should be considered so that is why proper management is required so that management tree should be formed and it is being formed for this you know that process design as a basic you know consideration.

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Step-by-step design strategy

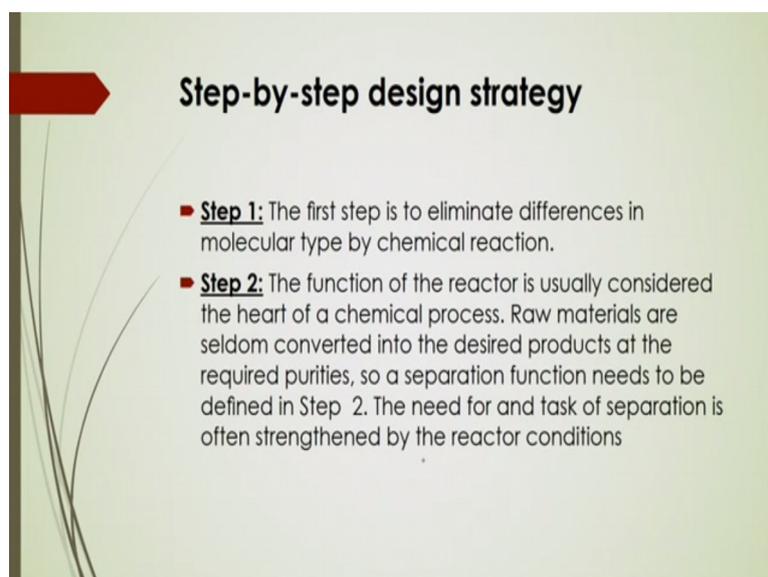
A systematic process design cannot be done in one step.

- Assume that the task of a process is to convert raw materials A and B into product C and to minimize by-product or waste D.
- The states of materials A, B, C, and D are defined by: mass flow, composition, phase (vapor, liquid, solid), form (e.g., particle size), temperature, and pressure
- The process design has to consider alternatives for raw materials and process routes that lead to a given product.

Now, step by step design strategy to be considered like you know that systematic process design cannot be done in one step, there are several steps to be consider here, in that case if you consider that the task of process where **your** conversion of raw materials, suppose A and B into product C and to minimize by-product or waste it is denoted by D.

So, in that case the state of the materials you have to know that whether this A B C are D are defined as mass flow composition phase form or temperature or pressure that you have to consider this you know that variables now this process is designed has to consider that alternatives for raw materials and process routes that lead to a given product.

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Step-by-step design strategy

- **Step 1:** The first step is to eliminate differences in molecular type by chemical reaction.
- **Step 2:** The function of the reactor is usually considered the heart of a chemical process. Raw materials are seldom converted into the desired products at the required purities, so a separation function needs to be defined in Step 2. The need for and task of separation is often strengthened by the reactor conditions

So for this you have to consider the step by step design strategy as a first strategy what you have to do that you have to eliminate the differences in the molecular type by chemical reaction now what will be the reactant and what type of reaction should be used what type of catalyst should be used what will be the solvent what will be the characteristics of the solvent if you are using catalyst what will be the size of the catalyst what will be the distribution of the catalyst particles everything should be considered and in that case some you know variable should be you know interacting to each other may be you know that suppose physical properties.

If you are using that slurry systems, if you are considering concentration you need not to consider the viscosity if you are considering the viscosity you need to not to consider the concentration because they are interrelated. So that is why you have to eliminate the you know that differences in the molecular type like you know the based on that physical properties like in that case you would have viscosity or other physical properties there.

And the function of the reactor as a second step should be considered in that case the heart of the chemical process, in that case you know that what type of function whether **these raw materials** are you know converted into the desired products and at the required impurities that how it will be you know that related to the other operating conditions.

Now may be you know that the yield is directly proportional to the you know that reactor conditions or you can say that the output of this or reactor performance or process performance is directly related to the hydrodynamics. **So**, you have to make a function like you know that process yield if you are considering that P process yield or Y that is a function of what is that different variables or it may be suppose physical operations the you know that efficiency of the absorption process.

Now that efficiency of the absorption process depends on mass transfer that depends on mass transfer coefficient that will be assist now this mass transfer coefficient depends on what this depends on you know flow rate of the fluid you know that geometry of the system like the size of the reactor length diameter even you know the distributor size of that you know that phases and also it may be you know that temperature dependent it may be pressure dependent it may be you know that physical property as a variable that will you know effect on that performance.

So all these things to be considered so in that case the process efficiency is a function of you know that velocity of the fluid whatever you know supply the size of the catalyst you know that size of the reactor may be diameter of the you know reactor even know the physical properties of the system like the density of the fluid you know that surface tension of the fluid you know that viscosity of the fluid and also you can say that some other mechanical provisions like you know that internal length or some other things. So, all these things to be considered so that is why you have to make a function based on your operating variables

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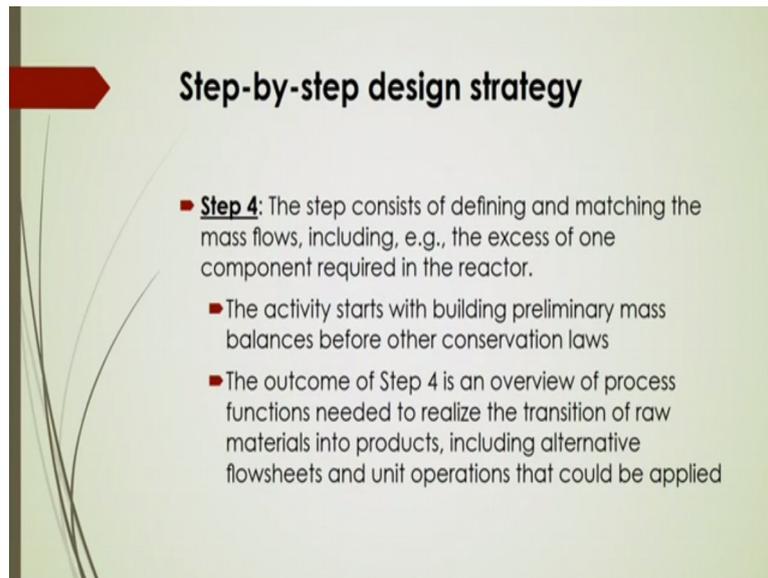
Step-by-step design strategy

- **Step 3:** Connections between process units are created in a third step while considering in detail the following aspects:
 - From raw materials to reactor: purification and conditioning of feeds (purification, heating, pressure)
 - From separator to product: final purification (finishing)
 - Reactor-separator connections: stream reconditioning (e.g., reduction of temperature and/or pressure)
 - Connections of separator outlets: reactor performance, excess components, recovery
 - Recycles from separators: connections to, e.g., reactor system

Now step 3 you know that you have to connect between process units and in that case from raw materials to the reactor purification and conditioning of the feeds to be considered there. Whether it should be you know that heat sensitive or pressure sensitive that you have to consider from separated to product, final purification that you have to consider based on your operating variables, reactor separator connections in that case process integration is coming and in that case how you are combining this 2 reactor and separator to get your you know that process design in that case you can reduce the temperature and the pressure.

Connections of the separator outlets, reactor performance process components, recovery and recycles from the separators connectors to other you know that system like reactor system or extractive system or some other things. So, in that case as a third step you have to consider the connections between the process units.

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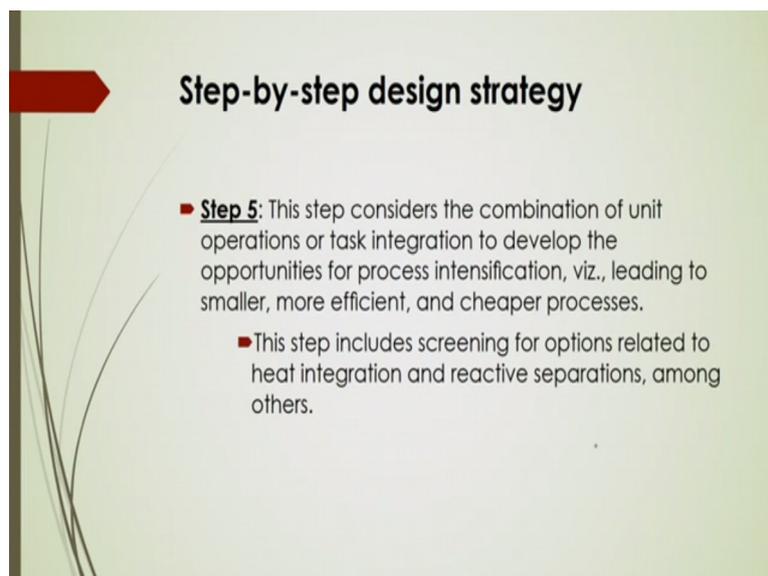


Step-by-step design strategy

- **Step 4:** The step consists of defining and matching the mass flows, including, e.g., the excess of one component required in the reactor.
 - The activity starts with building preliminary mass balances before other conservation laws
 - The outcome of Step 4 is an overview of process functions needed to realize the transition of raw materials into products, including alternative flowsheets and unit operations that could be applied

Step 4 what you have to do that you have to match the mass flow including that excess of one component that is required in the reactor suppose in the particular reactions excess amount of reactants to be required so you have to consider all those factors also so in that case activity and also a building preliminary mass balance is to be considered before other conservation laws you are assessing. **So**, the output of the step 4 is an overview of the process functions that will be needed to realize the transition of raw materials into products including alternative flow sheets and unit operations that could be of course considered.

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Step-by-step design strategy

- **Step 5:** This step considers the combination of unit operations or task integration to develop the opportunities for process intensification, viz., leading to smaller, more efficient, and cheaper processes.
 - This step includes screening for options related to heat integration and reactive separations, among others.

And next step is that the combination of unit operations or task integration to develop the opportunities for process integration like you know leading to smaller more efficient and you

know that cheaper processes, so this step includes screening for the options related to the heat integration or you can say that reactive separations or other you know that if you are using that like extractive distillation or you know that absorptive distillation all those things to be considered there as an integrated system.

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Step-by-step design strategy

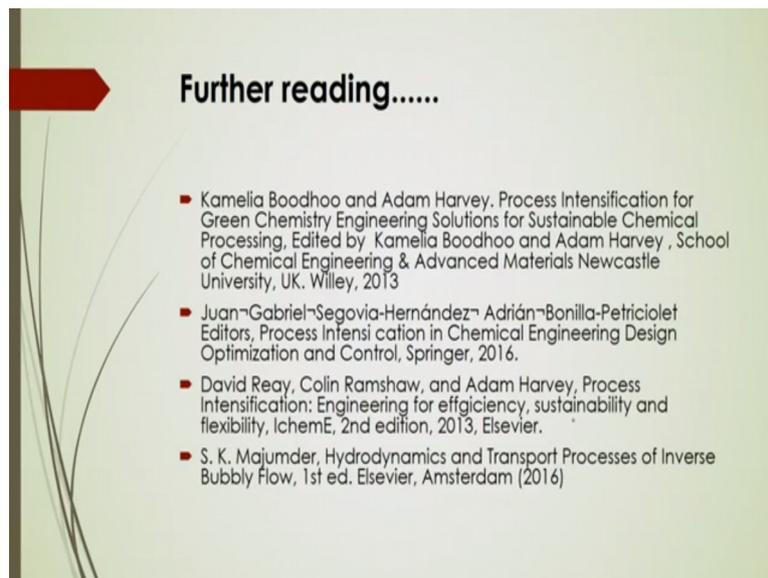
- **Step 6:** It consists of the setup of the mass and heat balances, and alternatives for the reaction and separation functions are considered.
 - Out of various process alternatives the most promising ones need to be selected taking into account profit, process yield, controllability, safety, and ecological aspects.

Between the steps, interactions will take place and decisions can create the need for loops to previous steps, e.g., to reconsider the reactions (Step 1) and separation (Step 2) in more detail.

And final step is that it consists of the setup of the mass and heat balances, and then based on that heat balance and mass balances and you have to you know that make a **function** of that you know process yield whether it is the separation or reactions or you know that combination of that reaction or separation or not.

Out of various you know process alternatives the most promising ones need to be selected by considering the profit, process yield, controllability and ecological aspects. **So,** between the **steps,** interactions will take place there and decisions can be you know considered where the need for loops to the previous steps is required and in that case with an example you can say that the consideration of the reactions for the step one and the separation as a step 2 to be known in detail.

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So, I think we have discussed here in this lecture that different strategies of the you know that process intensification for the sustainable development. So, I think you can get more information from this further reading oxygen these books. **So**, thank you giving attention for this lecture so thank you for that.