Chemical Process Intensification
Dr. Subrata K. Majumder
Department of Chemical Engineering
Indian Institute of Technology Guwahati
Lecture 10
Scales and stages of process intensification

Welcome to massive open online course on Chemical Process Intensification. So we have discussed in the previous module regarding different strategies of the process intensification. In this module, as a module four we will discuss something about the design techniques for the Process Intensification. So, in this module will discuss about the scales and stages of process intensification and also other phenomena or the process intensification.

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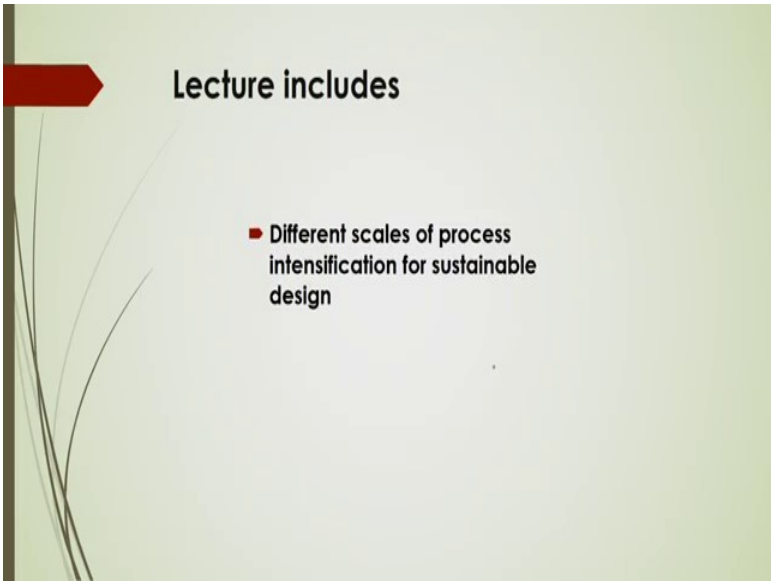

So, in this lecture on the scales and stages of the process intensifications will be discussed. So, we know that process intensification that happens with a different you know, that scales like it is micro, macro or you know, that meso scales except that, you know that some other parameters, so, based on these scales will be actually considered for the process intensification. So, in this regard, what are those stages for that scales that also to be considered here in this lecture.

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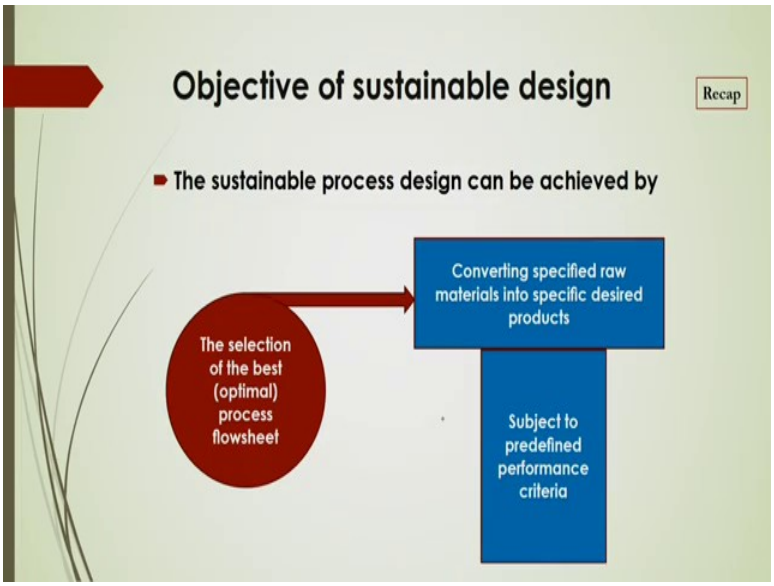

So, first of all we have to actually go back to the objective of the process intensification little bit because they are you know, that process intensification background depends on the, you know, different aspects of you know, that the strategies for the sustainable design. So, for that sustainable design, you have to go through some stages and scales.

So, that is why what are those objectives of that sustainable design that we have to know. We have already actually discussed about the selection of the best you know, that process for the sustainable development and in that case, what should be the optimal process flowsheet that also you have given in our earlier lectures. Even for that optimal process flow sheet what to consider, in that case, you have to convert the specified raw materials into a specific desired product based on the process intensification and the process techniques.

And also, this sustainable process design will be, of course, subject to the predefined performance of the, you know the process criteria. So, in that direction, that we have to actually consider that what should be the scales, whether it will be the meso scale or micro scale or some other way that process can be intensified for the sustainable design.

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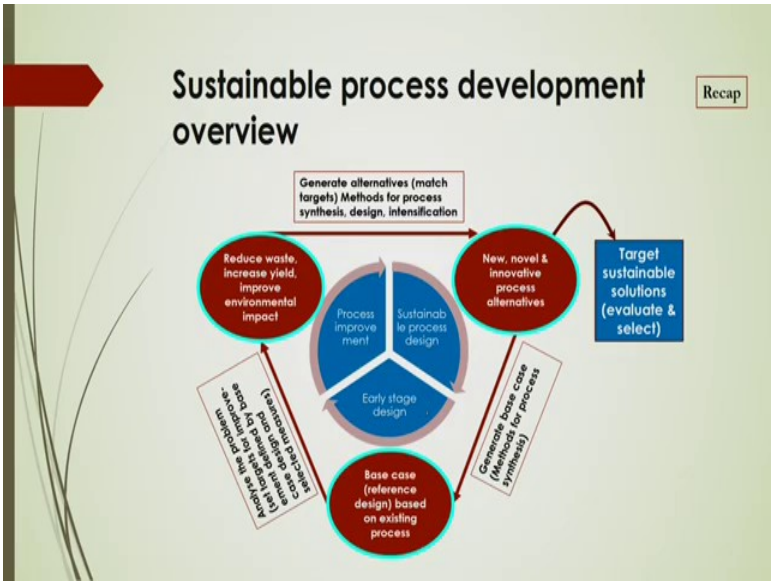

And that case, we have also discussed about that, there are basically three you know steps for that process development for the sustainable way in that case, you have to improve the process first and also that improvement may be from the you know, that existing process whatever available and from that you have to intensify the process to get the process improvement and then sustainable process design also there based on that early stage design.

So, what are the stages in earlier stage they have used, how to actually intensify, how to actually change that design to get the more sustainable way of the process intensification that should be considered. So, that we have discussed, so for this you know that process improvement or sustainable process design based on this earlier stage design, in that case, you have to, of course, the analyze the problem and by you have to set the targets of that improvement that will be defined based on the you know, that case designed.

Case designed also according to your you know, specific problem and in that case, main target of that sustainable process development to get the solutions and evaluate that process output or yield based on that you know, that reduction management of waste, even how to increase the yield, even also how to improve the environmental you know, that negative effect based on this sustainable development.

And also parallel you have to think about that, how to generate the alternatives way to actually get the better way of synthesis, even better way of design and better way of other yield of the process. So, in that case, new novel and innovative process alternatives should be actually thought about that. So, and all those things will be actually based on that, you know, that base case studies whether in the chemical process or some other mechanical process that should be considered.

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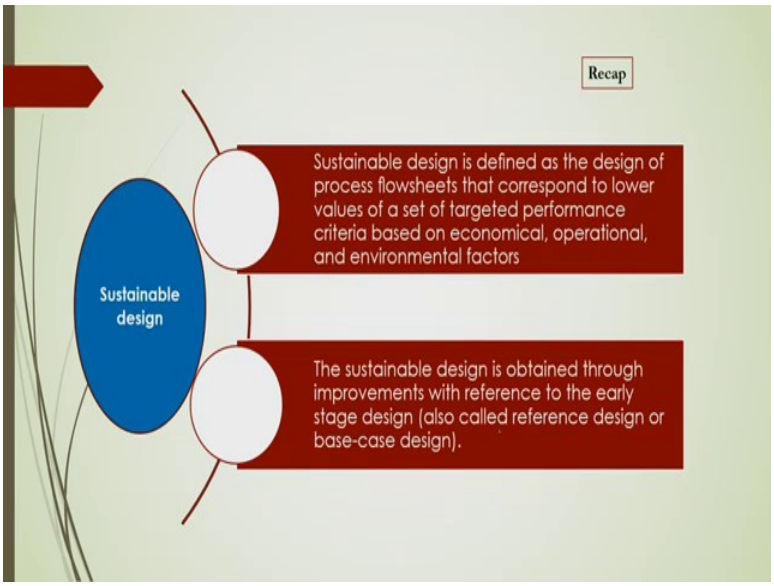

So, in that case, we know that sustainable design is defined as the design of process flowsheets that corresponds to lower values of set of targeted performance and also the criteria based on the economical, operational and environmental factors. So, the Sustainable Design is obtained through the improvements with that reference to the early stage design also called reference design or base-case design. And for that, you have to consider all those these economical, operational and environmental factors for that design.

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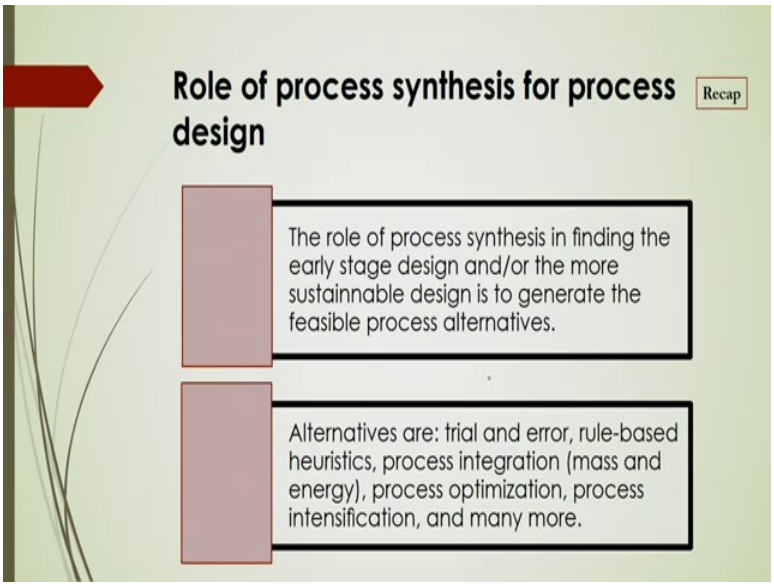

Now, what are those roles of process synthesis for the process design that also we have discussed to we have to know other things also, the role of process synthesis in finding the list is design and more sustainable design that is to generate the feasible process alternatives. And also, that alternatives are generally trial and error method, rule-based heuristics and also you know, process integration, mass and energy, process optimization, process intensification and also many more you can say so, these are the process synthesis role for the process design.

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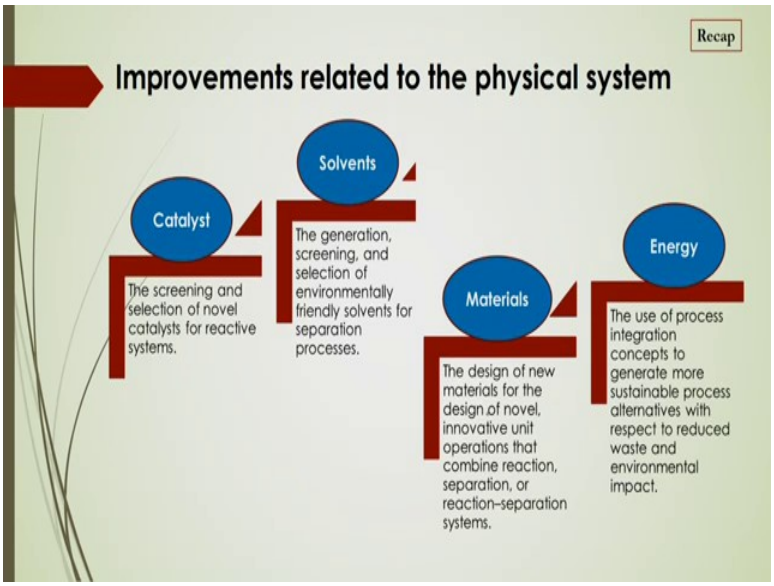

And also, the improvements that process designed are related to the physical system like you know, that what are the materials you are using and all sort of the solvents you are using, what are the energy that you are going to consider for that, you know, that economic consumption of the energy so, that should be considered also.

So, if you are synthesizing some catalyst that the screening and the selection of the novel catalyst for the reactive system, that you have to you know, consider and also what will be the characterization of what those catalyst particles that also to be considered for the process design. And what are the solvents that you are going to use for that particular process that also to be taken care, because some solvents may be hazardous and some solvents may be giving the less intensity of the, you know, that super availability of the compound from the other components.

So, in that case, the integration generation of the screening and the selection of the environmentally friendly solvents that is not hazardous that you have to consider for the separation process and materials, the design of new materials of course, to be considered for that design of novel innovative unit operations and in that case, you have to integrate those things like combination of the reaction, combination of the separation and also reaction separation, both things.

That is why the reactive distillation, reactive extraction even you know that reactive adsorption that is reaction as well as adsorption both operations are coming up for that, you know, simultaneous operation of these unit operations. So, in that case materials should be used properly where that reactions, whenever reactions will be going on whether those materials will be converted to other materials or not, because that materials may be used for separation, but those materials may be reacting with the other you know that reactants.

So, that is why whenever you are considering the integrated process of that reaction, as well as, you know, that separation process. So, you have to think about that, like you know that there is an example you are suppose ozonation, you know, that there is a you know, application of process intensification of like advanced oxidation process in that case, sometimes you know, micro bubble systems, micro cavitation they are, ozone micro bubbles are produce into actually convert the arsenic 3, which is naturally you know, that available in the groundwater that arsenic 3 is to be converted to the arsenic 5 so, this is the reaction parts,

Now if you are considered the reaction as well as adsorption of that, what is that derivative of that arsenic 3 to the arsenic 5 that arsenic 5 to be adsorbed on this some other materials like if you are using the resin materials, then you have to think about that, that whenever you are going to combine these processes, whether this resin materials, which is being used for that adsorption purpose should not be actually converted by advanced oxidation of ozone. So, that should not be reacting with the ozone gas.

So, that is why you have to think about the materials, whenever you are going to use for separation process after reactions. So, in that case for design of that particular process, that the consideration of the material properties are very important. And in that use of the process integration that you know sometimes you know, to create more sustainable process alternatives.

In that case you have to use some energy, maybe that energy will be more consumed or maybe sometimes the if you are integrating the process less number of equipment should be used in that case less energy may be used. So, that energy consideration also to be

taken care of improvement of the you know process designed for the process intensification.

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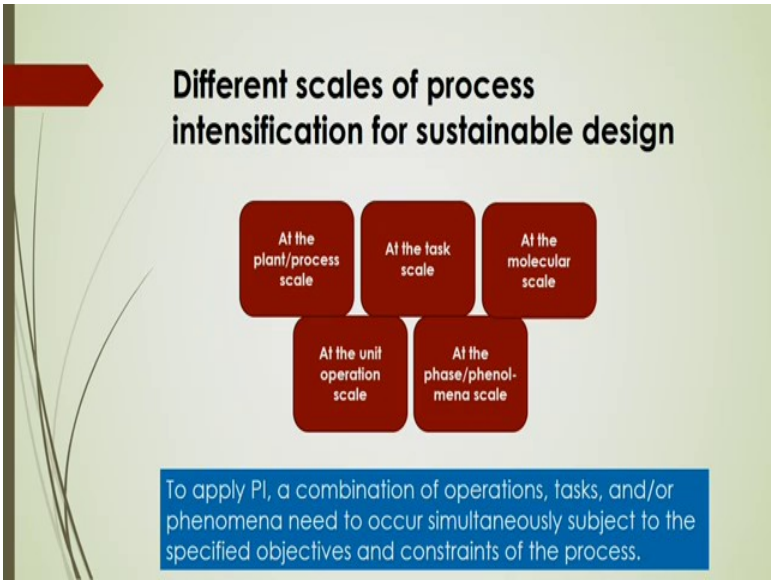

Now, what are the different scales of the process intensification for sustainable design? You know that different stages, different you know that scale you have to think about that for the process intensification at the plant processes scale, at the task scale and the molecular scale because there are three actually scales are available to get to the Sustainable Design for the process intensification.

So, at the unit of operation scale and other the phase and phenomena scale are actually conjugated to that, you know that the task the scale and molecular scale, though we have we can subdivide this you know that the different you know scale as that plant scale, task scale and molecular scale and also unit operational scale and also up in phenomena scale.

Now, to apply the process intensification, a combination of the operations, tasks and all phenomena based you know scale need to occur simultaneously subject to the specified objectives and constraints of the process. So, whenever you are considering you know that process intensification at this various stages or various scales that in that case you have to consider what are the objectives and constants of the process. So, that should be

actually taken care for the analysis of process yield based on this different stages or scales.

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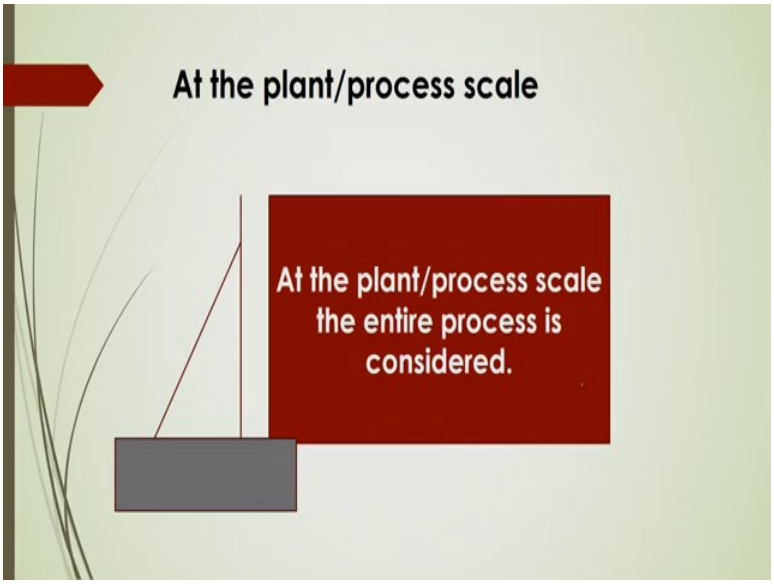

Now, at the plant or processes scale, in that case all the plant to scale you have to consider the entire process. What are the entire processes? Like here maybe reaction, maybe adsorption, maybe extraction, all the process at a time you have to consider at the plant or process scale.

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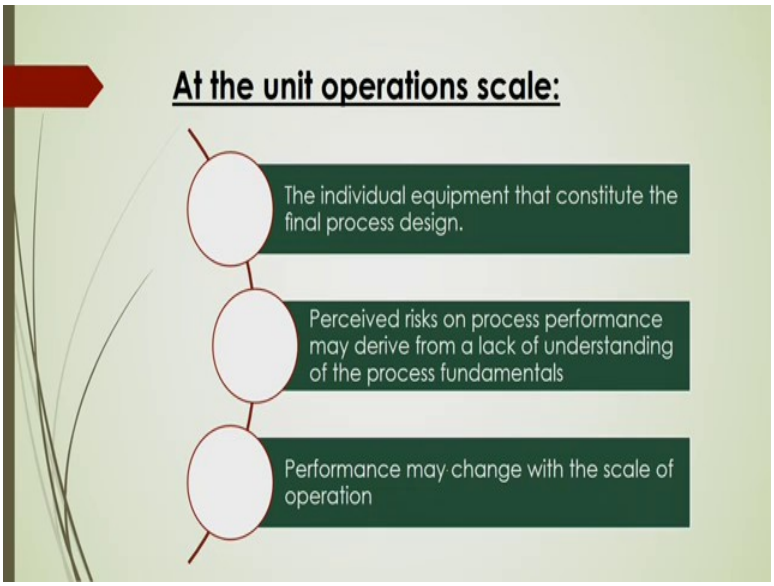

And at the unit operation scale in that case individually equipment that constitute the final process design should be considered and also for you know perceived risks on the process performance can be derived from a lack of understanding of the process fundamentals. And also, in that case you will see the performance of the unit operations may be you know that there are several unit operations like you know that extraction process is one unit operation.

Mass transfer is one-unit operations, you know that adsorption is one-unit operations; heat transfer is one-unit operations. So, in that case the performance all those unit operations may change with the scale of the operations, that is why macro to micro even nano scale stage is coming. So, in that case performance of the unit operations depends on the scale of the operation.

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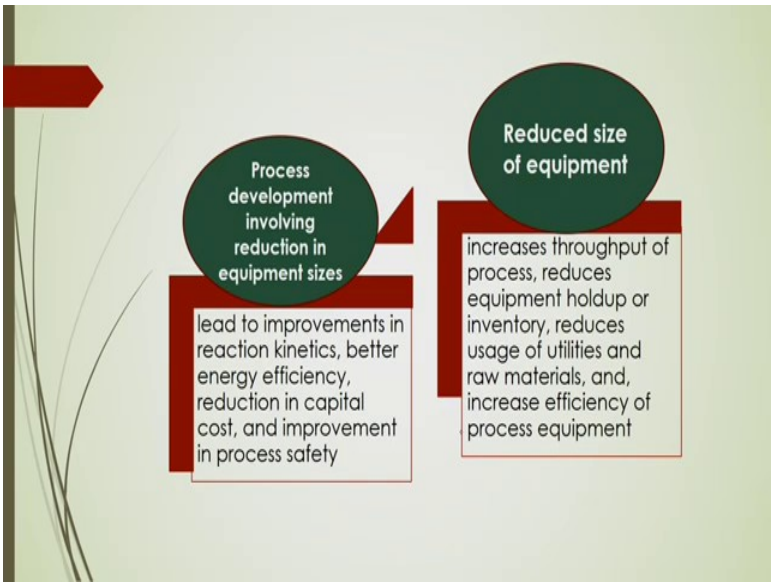

Now, process development involving reduction in equipment sizes in that case one scale for that unit operation, this actually led to improvements in reaction kinetics, better energy efficiency, you can see reduction in capital cost and improvement in the process safety. So, this process development involving the reduction equipment size will give you this benefit.

And also if you reduce the size of the equipment in that case it will increase the throughput of the process and also it will reduce the you know equipment hold up or inventory you can say and also reduces the uses of you know utilities and raw materials and also in that case, the process you know that equipment efficiency also will be increased by reducing the size of the equipment.

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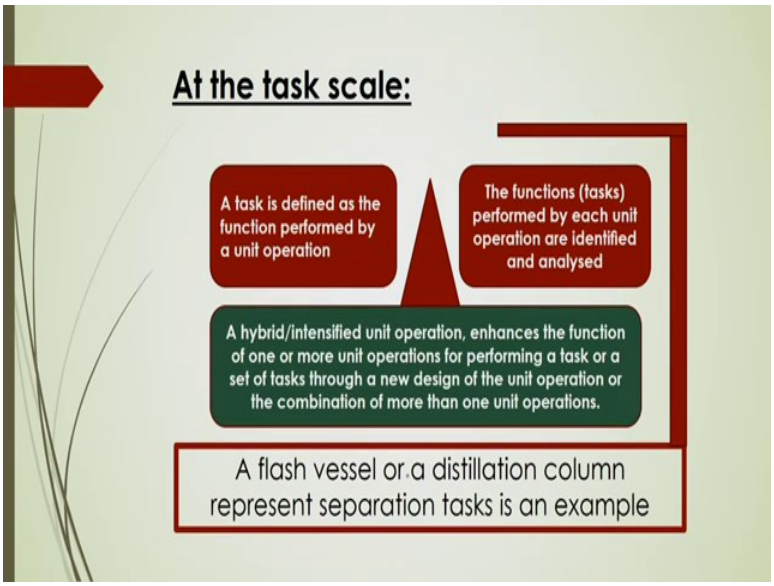

Now, at the task scale, what is that? You know that at the task scale generally it is defined as the function that performed by a unit operation. Like you know that if you are supposing a design and equipment based on this process intensification way that what will be the that efficiency of that process or yield of the process. Now, you have to make a function that will be depending on several you know factors, that functions that is called tasks that performed by each unit operation that should be identified and analyzed based on the operating variables.

So, a hybrid or intensified unit operation if you are considering in that case, it will enhance the function or one, or more unit operations for performing a task or a set of tasks through a new design of the unit operation or the combination of more than one-unit operations there. So, that is why at that task scale, you have to think about that, whether you are going to design the process as a hybrid or intensified unit operations or not.

So, in that case, if you are considering then you have to enhance the function of one or more unit operations for the performing a task or a set of tasks through a new design of that unit operation. Now, if flush vessel or a distillation column that represents the separation tasks is an example here. So, separation tasks, what is the (pros) separation efficiency, that distillation column will give you that separation efficiency.

Now, that separation efficiency depends on several you know that factors whether you are reducing the capital cost, whether you are reducing the material used, to reducing the you know that equipment size, whether you are using you know that some other materials or you are using design or design that unit based on the other you know geometric variables or not. So, all those things to be considered to actually analyze these tasks.

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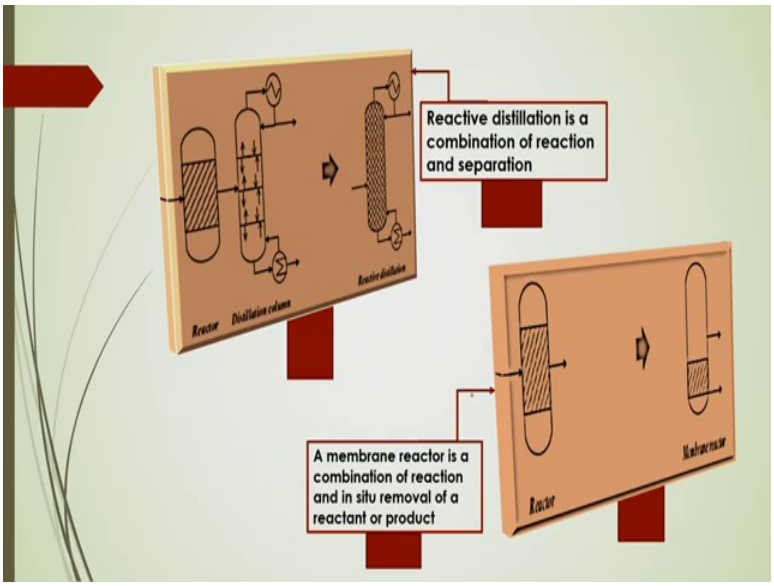

Now, reactive distillation is a combination of the reaction and separation in that case, what are the efficiency of that you know integrating system of reactive distillation based on you know that reactor size, distillation column size and different operating parameters. And if you are conjugating this unit operation, you will get the one single unit and that single unit will give you the better way of that process designed to get the better yield.

Similarly, other membrane reactor is also one combination of reaction in situ removal of reactants of products based on this membrane you know that efficiency. There are several membranes, of course, will come, maybe you know that ultra and even nano filtration based on you know that membrane. So, there are different types of membranes that will give you the enhancement of the process and also your design will be a sustainable design based on these.

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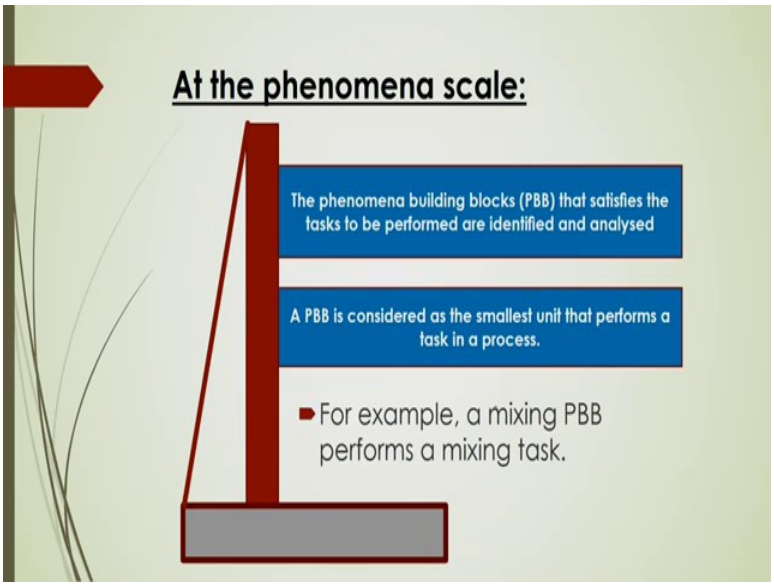

At the phenomena scale, the phenomena you know that in that case you have to build a certain block, that concept block you can say or phenomena building blocks, that satisfy the tasks to be performed or identified and analyzed. So, in that case, you have to think that different you know, building blocks like you know that separation, you know that reaction, you know that mixing, you know that heat transfer, so all other you know that phenomena to be considered as that phenomena building blocks.

So, you have to that identify and also analyze those, you know that phenomena-based building blocks whenever you are going to, you know that synthesize any chemicals based on the process intensification. So, in that case these phenomena 'building blocks' is considered as the smallest unit that performs a task in a process. So, that is why in that suppose a mixing, phenomena building blocks performs a mixing task there.

So, how mixing whether this mixing can be intensified or not, whether you can reduce the back mixing or not, whether you are designing the equipment, you are designing the device in such a way that your, you know that back mixing will be less. So, you can provide some provision of mechanical parts where that you know that internal circulation of the fluid elements will be reduced to get the reduced back mixing. So, this mixing task

will give you that you know that phenomena-based building block for the conceptual you know process intensification and sustainable design.

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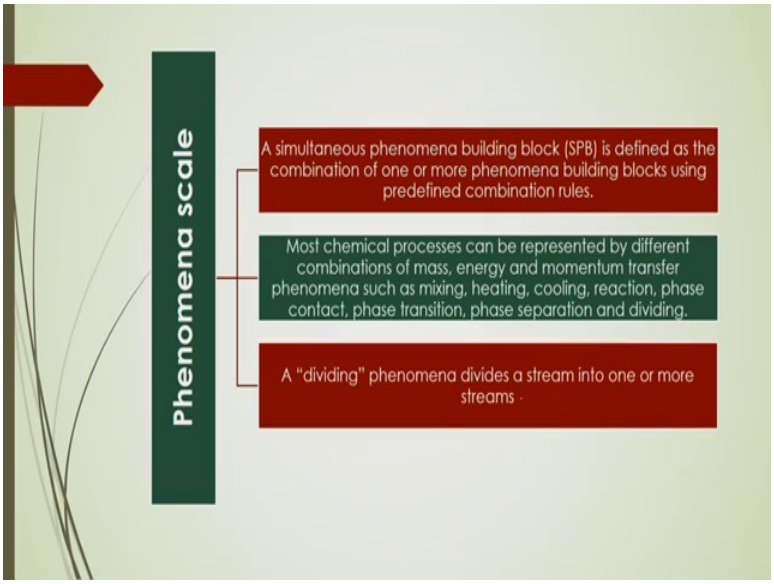

Now, what that phenomena scale actually if we consider the simultaneous phenomena building blocks in that case combination of one or you know more phenomena building blocks to be considered as a whole for analyzing the whole process intensification or whole design. So, in that case you have to you know predefined the combination rules either way whether after reactions it will be adsorption, after reaction it will be mixing, after reaction it will be that adsorption or after mixing it will be some other chemical operations or not.

Or to get the certain process output whether that mixing separation reactions all those things to be considered at a time or not and how it will be actually interacting and also the effects on the process output there. So, simultaneous phenomena building block mixing as well as you know that fluid flow phenomena, flow patterns that should be considered.

So, simultaneous phenomena should be considered for the process design there, most chemical processes can be represented by different combinations of mass, energy and momentum transfer in that case phenomena like you know that mixing, heating, cooling

reaction, phase control, phase transition, phase separation and dividing rules should be considered for the process design.

A dividing phenomenon divides a stream into one or more streams. So, that also to be considered. Suppose, you want to segregate that fluid stream, so you have to consider the divider. So, dividing tools also should be there for the considering of the process design as a phenomena scale.

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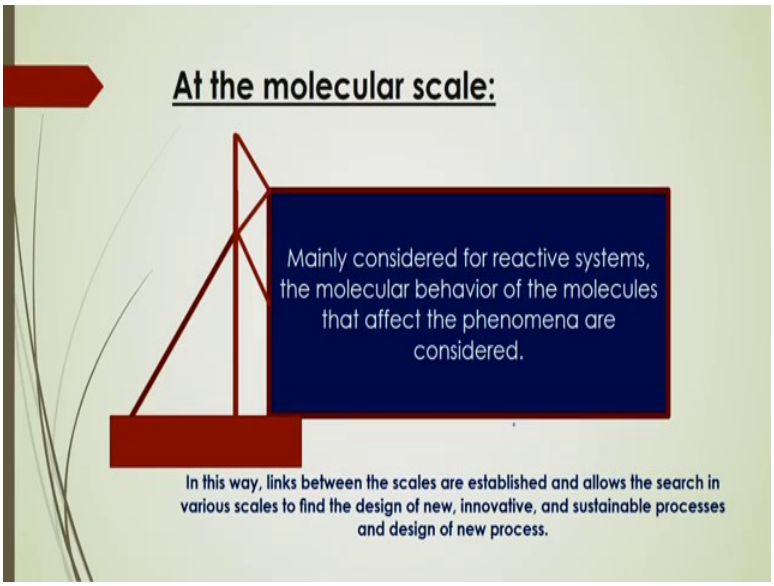

And at the molecular scale mainly considered for the reactive systems here and in that case the molecular behavior of the molecules that affect the phenomena are considers. So, in this way you can the links between different scales are generally established and it will allow the source in the various scales to find out the design of the new innovative and the sustainable process and design of the new process. So, that is why you have to first think about the how actually all those you know, scales are linked before that going to the design of that sustainable process.

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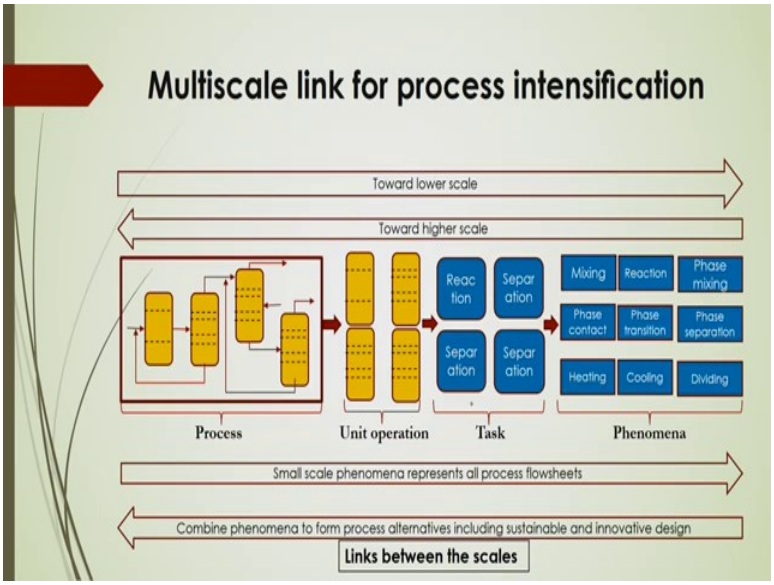

Now, let us have this links between the scales by this process diagram here, you will see if we divide it a certain process into different scales like processes scales, unit operations scale, task scales and phenomena scales. So, in this case, you will see that in the process scales, there may be you know, that reactions, there may be you know, that some other chemical synthesis process and the reactor.

So, or what are the different you know, unit operations to be considered there and after that unit operations that maybe different types of unit operations will be considered there like after integration, after reactions, what type of unit operation to be considered for the separation of that products and that separations will depend on the different tasks.

Like you know that reactions, separations and separation (separate) different types of tasks will be there and that tasks based on the operating variables have what is called the phenomena based like hydrodynamic, so, in that case mixing, reaction, phase mixing, phase contact, phase transition, cooling, heating even dividing of that fluid streams, flow pattern so, all those things to be considered based on the phenomena.

Like what type of fluid are giving that you know that reaction, what types of fluids and based on the fluid properties, how it will be actually changing the mixing characteristics,

how phase contact will be there whether it will be miscible or immiscible, whether it should be any change whenever it will become from the liquid to the gaseous phase.

So, at that phase transition, what will happen that should be considered? Even during that phase separation, what actually a residence time of that you know, contact of the phases, what should be the you know, that heating energy to be considered, the cooling energy to be considered for that particular phase separation. So, it is to be considered.

So, there are these 4 tasks, 4 you know that scale at these four scales, we are going to consider the you know that reaction scale, unit operation scale, tasks scale and phenomena scale. So, in this case, if you go from the you know, lower scale to the higher scale, you will see all those things to be considered here reaction, mixing phenomena, phase mixing phenomena, phase transition, dividing, cooling, heating all those phenomena.

Whereas, if we are considering the scale to the process, without considering all those you know that phenomena or task, then you can also get the overall output, but to get the you know, that intensified way of output you have to consider this task phenomena scale. So, that is why there is a link between this process unit operation task and phenomena.

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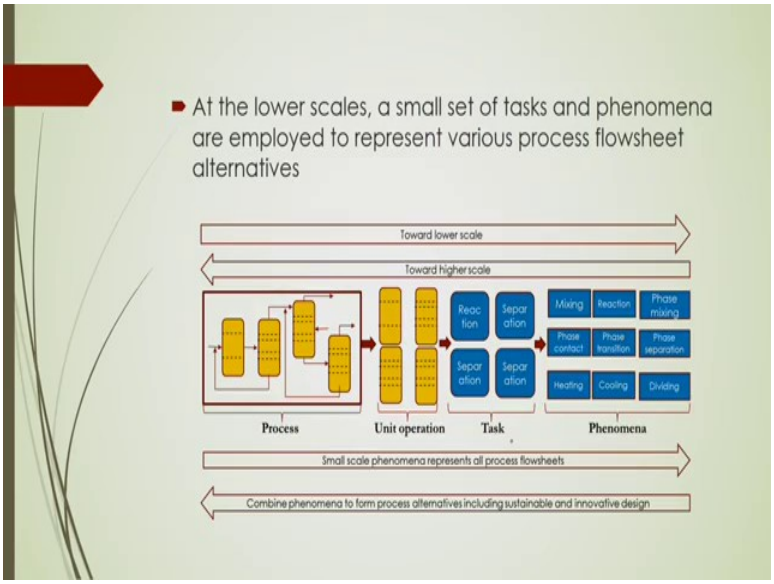

So, at the lower scales small set of task and phenomena are employed to represent various process flowsheets alternatives. So, in the you know task scales, you can consider that flowsheet of reaction, flowsheet of separation, flowsheet of you know that heating, flowsheet of cooling, all those things. Now, all those things flowsheet, it depends on that mixing and cooling, heating and energy supply there. So, at the lower scales, you have to consider the alternatives of a small set of tasks and phenomena.

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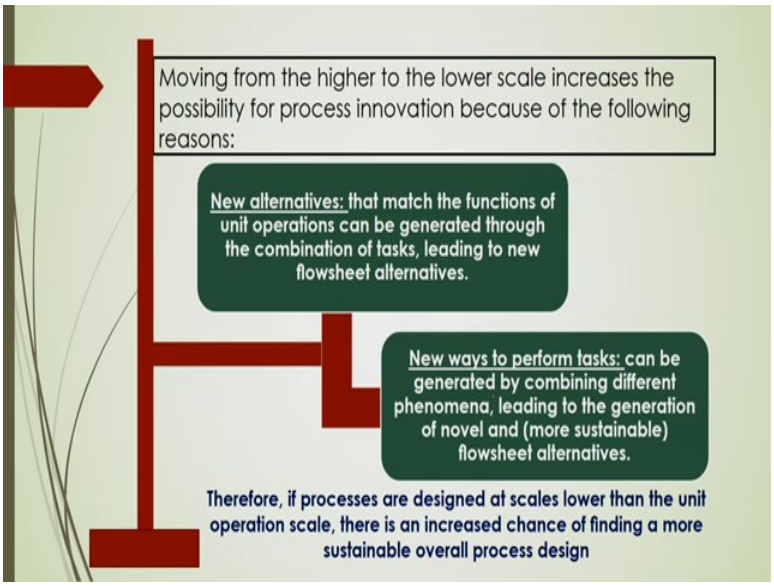

Now, moving from the higher to the lower scale, that will increase the possibility of the process innovation, because, in that case, you know, that functions of unit operations can be generated through the combination of tasks leading to new flowsheet alternatives and also if you are thinking about a new ways to perform tasks in that case, the generation of that tasks can be done by combining different phenomena leading to the generation of novel and more sustainable flow sheet alternatives.

So, therefore, if processes are designed at a scale that is lower than the unit operations scale, there is an increased sense of that finding a more sustainable overall process design there. So, it is very important that always if you are going to the lower scale from the higher scale, that your thinking of new alternatives and also new ways of performing the tasks to be considered.

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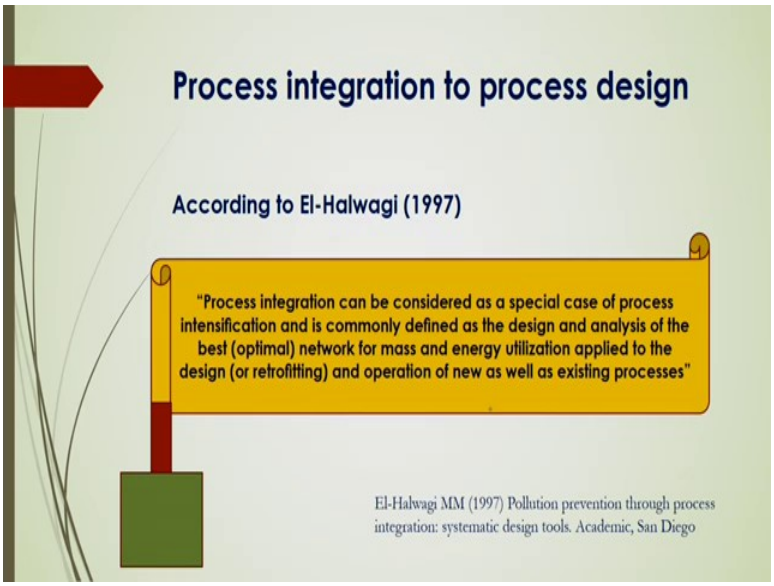

Now, process integration can be you know, that considered and other special cases according to the you know, that a El-Halwagi, he actually given that some statement for this the process integration to process design there so, according to him that the process integration can be considered as a special case of process intensification.

And is commonly defined as the design and analysis of the best network for the mass and energy utilization that is applied to the design and operation of new as well as existing processes. So, that is why the process integration is one of the important you know, that backbone of the process design for the intensification of the process.

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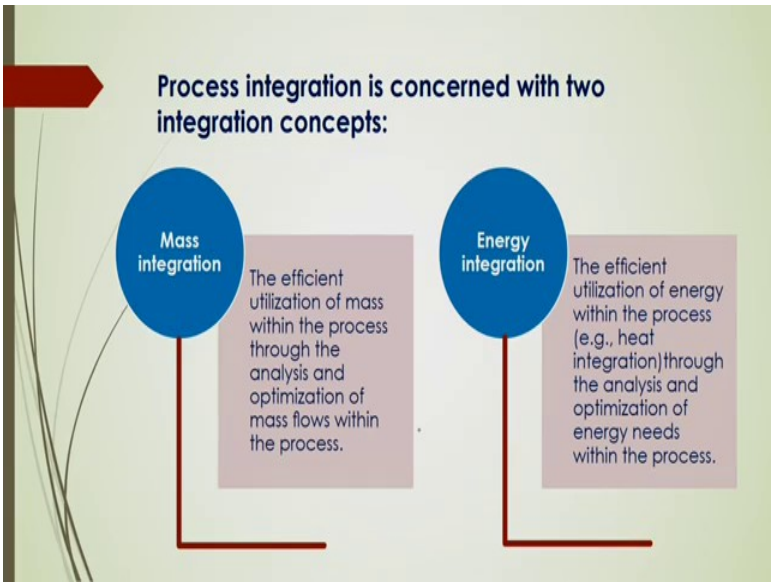

Now, in that case this process integration is concerned with two integration concepts, one is mass integration and other is energy integration. So, for the mass integration, the efficient utilization of the mass to be considered here within the process by analyzing and optimizing the mass flows within the process and also in the case of energy integration, the efficient utilization of the energy to be considered like you are if you are using heat energy, then you have to integrate that heat part where by the one process, if heat is releasing that releases heat how to actually utilize for the second process.

So, that should be considered that is why energy integration concept is coming, because that wastage of the heat energy, wastage of the energy to be reused for the other process. So, based on that energy integration process, this you know, that process integration can be designed. So, that is why efficient utilization of the energy within the process through the analysis and optimization of the energy needs within the process.

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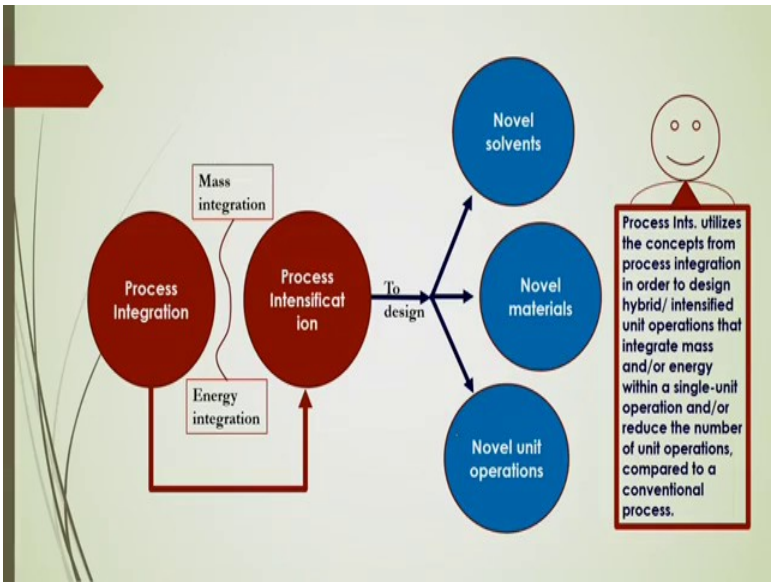

Now, another important point which is to be remembered, whenever you are considering that process intensification for the utilization of the concepts from the process integration. So, in that case, in order to design that, you know, hybrid or process integration or intensified unit operations, that should integrate the mass and energy within a single unit operation or you can reduce the number of unit operations by just conjugating that two or more unit operations in a single unit, and also how it will be intensified that also to be compared with the existing process.

So, to analyze those that process integration, whether it should be intensified or not, what times of that or what will be the factor of that intensification that also to be considered for that based on the existing conventional process. So, if you are considering the process integration that should be actually conjugated with that mass integration and energy integration and to give you the process intensification.

And to design of that process integration unit in a sustainable way, that you have to consider that novel solvents which are being used novel materials, which is to be used and also novel unit operations like weather equipment, what type of movements and what are the different processes, as well as for the mass transfer and heat transfer. So, all those things to be considered for the, you know, that process integration.

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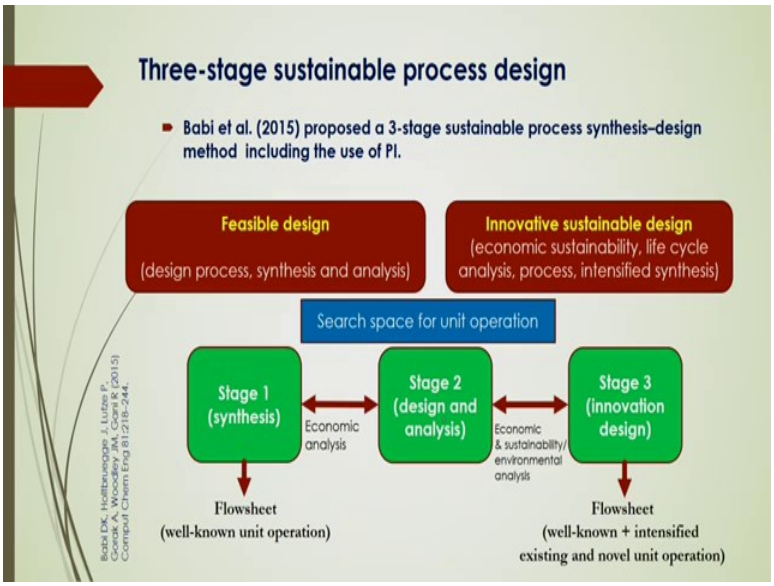

There are three stages sustainable process designed for the process integration, in that case, you have to consider that feasible design in that case, you have to think about that, how to design that process, how to synthesize the process, and also you have to analyze that process for the feasible design and also for the innovative sustainable design, that you have to think about that whether it should be economic or not, whether it should be lifecycle based or not, that lifecycle analysis should be required and also intensified synthesis to be considered for that.

So, according to you know, that Babi et al 2015 that for the feasible design and innovative sustainable design based on these design process, synthesis and analyzes and also economic sustainability and also life cycle analysis, they actually suggested that, you have to search some space for that unit operations by stage. In that case he has suggested the three stages for the synthesis for the design and analysis and innovation of design.

So, for the first stage according to them that they told that some flowsheet should be considered and for that particular well-known unit operation and based on that economic analysis, you have to design that integrated system in a stage two based on the second economic analysis and after that, you have to design that system in such way that you have to consider the flowsheet.

Well known intensified existing and novel unit operations there and based on which you have to couple this flowsheet well known and intensified existing a novel unit operation for that innovative design. So, according to that Babi et al, we can say that to search that unit operation for the feasible design and innovative sustainable design, you have to consider the flowsheet, you have to consider the intensified existing and novel unit operations for that.

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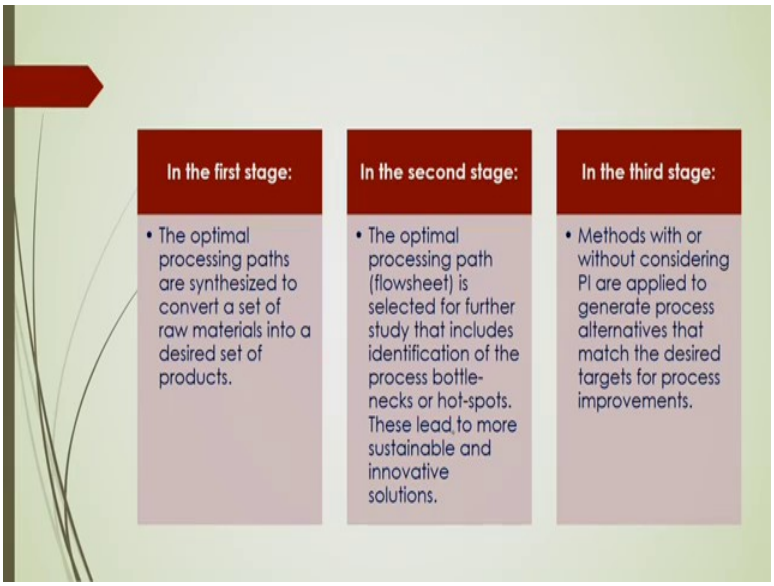

Now, in the first stage, you have to consider the optimal processing parts for that, you know, flowsheet and which has to be actually synthesized to convert a set of raw materials into a desired set of products. Now, in the second stage that optimal processing path that is called flowsheet to be selected for further study.

And also includes the identification of the process bottlenecks or hotspots like is there any uniformity of the distribution of the heat or energy or mass is there or not, and these will actually lead to more sustainable and innovative solutions. And at the end of the stage, you have to consider the methods that the process intensification can be applied to generate process alternatives, and also the desired targets for the process improvements.

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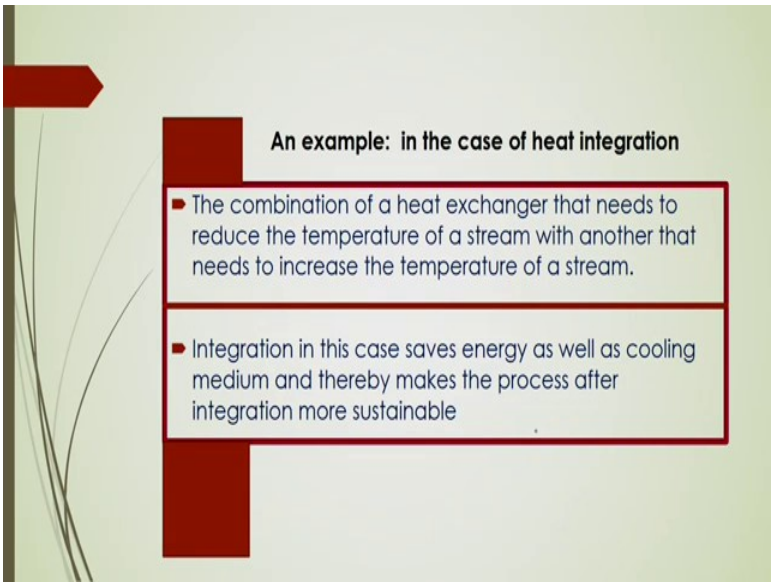

As an example, if we consider the case of heat integration. So, in that case, we have to consider the combination of heat exchanger as an example, that needs to reduce the temperature of the stream with another that needs to increase the temperature of the stream that means, from the one unit whatever fluid steam is coming, if its temperature is higher and that temperature, if you are going to utilize for the second operation, second stream like sub unit one and unit two.

In the unit one output streams having the temperature higher than the you know that unit one, in the unit two if you suppose want to cool down the or if you want to you know that reduce the temperature of that process, then you can easily supply this output heat energy to reduce that second operation in such way that some cooling materials to be used there. So, in that way that you have to combine the heat exchanger where output energy can be used for the other operations, so, integration in this case saves energy as well as cooling medium and thereby makes the process of integration more sustainably.

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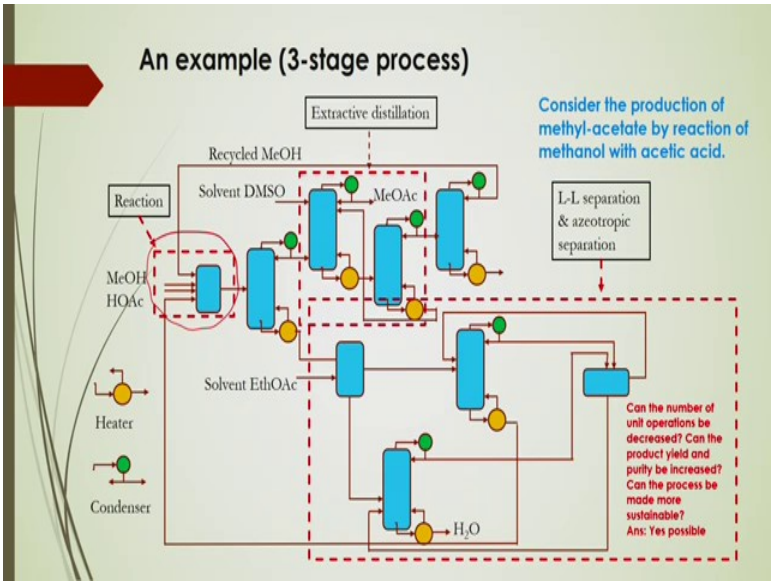

Now, here is an example of three stage process is given for the production of methyl acetate by reaction of methanol and acetic acid. Here see the process flowsheet, in this case, and the first stage you will see and there is a reaction scale, here in this case methanol and you know acetic acids are used this reactor and after that reactions you know that some ethanol or ethyl acetate will be formed and that ethyl acetate with solvents that will be you know that separated by some other unit operations there, in this case, this is called unit operation stage that is called extractive distillation.

And after that, there will be several other unit operations where you can segregate or you can separate those you know, products and byproducts by several you know, that unit operation. So, in that case, you will see a number of unit operations, the decreased by just integrating those process in a single unit and, of course, yield of the product should be increased to its certain level of purity. And also, can the process be made more sustainable?

Of course, the process can be more sustainable based on this you know that process integration, if you are doing individual operations separately and if you are considering all these or materials and energy then you can get there is a chance to you know that loss of more energy, loss of more materials and the loss of more you know that capital. So, in

that case, you have to integrate all those separate process in a you know that integrating way so, that you can save your energy and also you can improve yield of the process.

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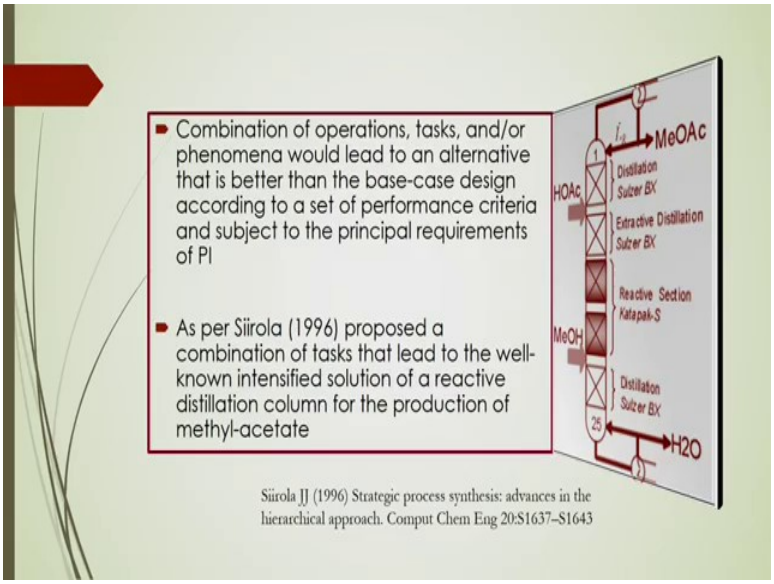

Now, another example combination of operations tasks and or phenomena would lead to an alternative that is better than the base-case design according to a set of performance criteria and subject to the principal requirements here. And in this case, you will see that there is synthesis of methyl acetate based on this extractive distillation. So, distillation as well as extraction will be happening along with that reaction.

So, reaction, distillation and the extraction three units will be working at a time here in a single unit. So, in that case, you know that operation task and phenomena will be considered to design this process integration for that process intensification process as per you know, Siirola proposed a combination of tasks that lead to the well-known intensified solution of a reactive distillation column for the production of methyl acetate here.

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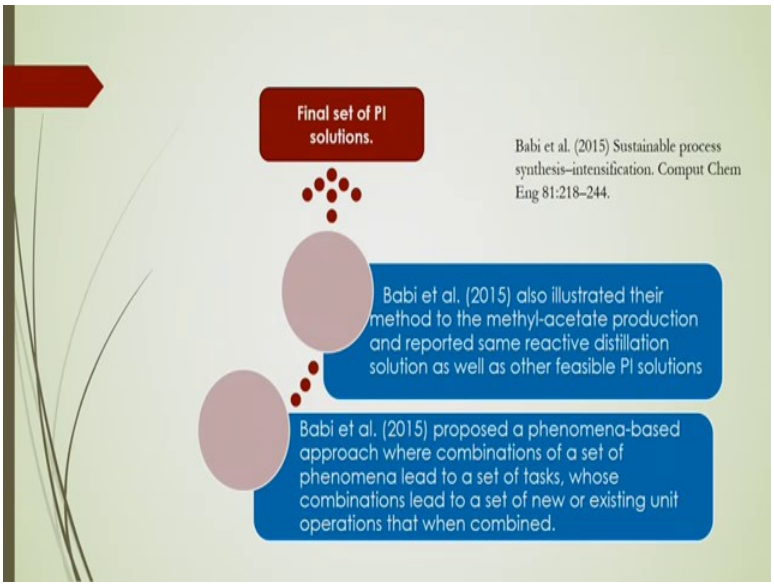

And for the final set of process intensification, solutions based on this you know process integration Babi et al proposed a phenomena-based approach where combinations of set of phenomena lead to a set of tasks whose combinations lead to a task of new or existing unit operations, when it will be combined.

And also, they have suggested or illustrated their method to methyl acetate production that has been shown in the previous slides and reported the same reactive distillation solution as well as you know, the other feasible process intensification solution. So, to get the final set of process intensification solutions, you have to consider the process integration and also phenomena-based approach will be the better way to think about the combination of the process or integration of the process.

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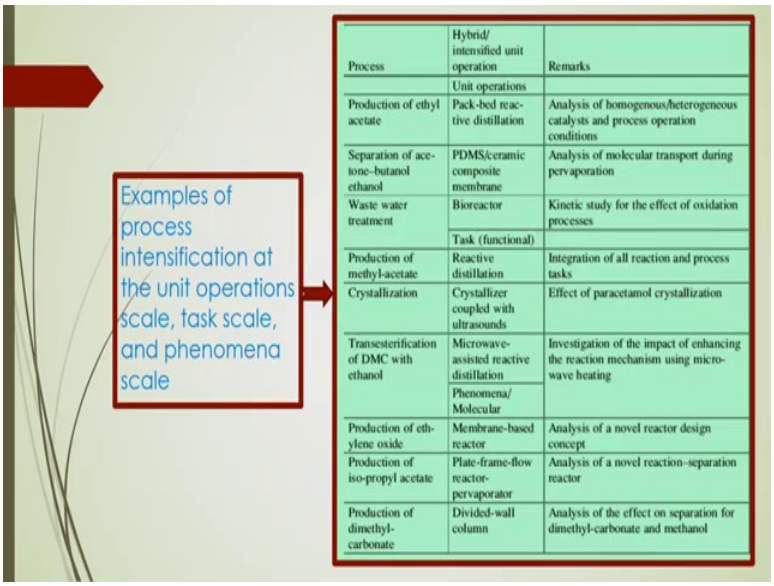

Process	Hybrid/ intensified unit operation	Remarks
	Unit operations	
Production of ethyl acetate	Pack-bed reactive distillation	Analysis of homogenous/heterogeneous catalysts and process operation conditions
Separation of acetone–butanol ethanol	PDMS/ceramic composite membrane	Analysis of molecular transport during pervaporation
Waste water treatment	Bioreactor	Kinetic study for the effect of oxidation processes
	Task (functional)	
Production of methyl-acetate	Reactive distillation	Integration of all reaction and process tasks
Crystallization	Crystallizer coupled with ultrasounds	Effect of paracetamol crystallization
Transesterification of DMC with ethanol	Microwave-assisted reactive distillation	Investigation of the impact of enhancing the reaction mechanism using microwave heating
	Phenomena/ Molecular	
Production of ethylene oxide	Membrane-based reactor	Analysis of a novel reactor design concept
Production of iso-propyl acetate	Plate-frame-flow reactor-pervaporator	Analysis of a novel reaction–separation reactor
Production of dimethyl-carbonate	Divided-wall column	Analysis of the effect on separation for dimethyl-carbonate and methanol

Here are some examples of process intensification of given for the unit operations scale, task scales and phenomena scales like he has some process hybrid or intensified unit operation that is called integrated process. Some you know, that opinions are given here based on these different processes like if you are producing some ethyl acetate in that case, pack bed reactive distillation can be designed as an integrated system for the analyzes of homogeneous and heterogeneous catalyst and process operation conditions.

In that case, you can get the more process yield for the production of ethyl acetate. And also, for the separation of acetone butanol ethanol in that case PDMS or ceramic composite membrane can be considered as a process integration and that case molecular transport during the pervaporation is actually being analyzed.

For the waste water treatment like bioreactor and in that case, (tasks) you have to consider for the process integration, and in that case kinetic study for the you know, that effect of oxidation process to be considered. And also, production of methyl acetate for the task or functional that is reactive and distillation both should be considered as a functional task.

And in that case, all reaction and process tasks to be integrated, crystallization in that case, crystallization should be coupled to the ultrasounds process and in that case effect of you know that paracetamol and you know, that paracetamol crystallization to be considered. And you know transistor invocation of DMC with ethanol also it is one of the important process where microwave systems to be considered for the intensification.

In that case, phenomena based or molecular based tasks we considered. In that case impact of enhancing the reaction mechanism based on the investigation of this you know that microwave concepts and also you know that reaction mechanism will be considered based on that microwave heating.

And the production of ethylene oxide also important application for the membrane best reactor development and that case analysis of novel reactor design should be you know that considered for each conceptual design and also a production of isopropyl acetate in that case analysis of the reaction and separation in that particular reactor of plate frame flow reactor for that pervaporation of this production of isopropanol or isopropyl acetate.

And also, there are important you know that hybrid operation is called divided wall column in that case dimethyl carbonate is being actually produced based on this divided well column in that case effect on separation for the dimethyl carbonate and methanol is analyzed for that process integration, for the process intensification process. So, these are the different you know, that applications based on the hybrid or intensified unit operation and what are the different design consideration that has been given here.

So, I think it will be better to know that for the sustainable design based on that different scales to consider those you know that offer it in variables and also that you know that some parameters based on the tasks, phenomena-based tasks would be considered there. So, they are some mixing characteristics and it is depending on the physical properties of the system, depending on the geometry of the system, depending on the other parameters like energy distribution, all those things to be considered there.

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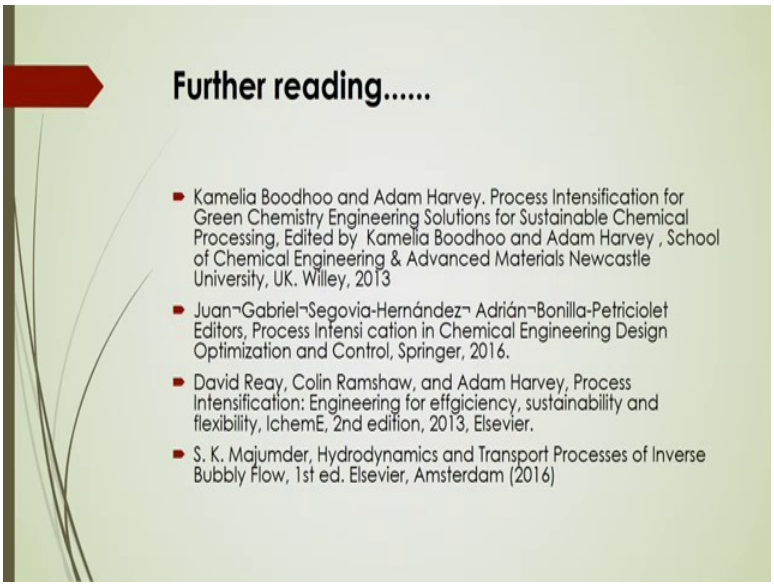

So, I would suggest to know about this more just going by this part the reading of this text books given here. So, I think you understood some extent of this process intensification design based on the sustainable concepts of you know designing that process for this process intensification. So, next lecture onward will discuss something more about the, you know that design techniques of this process intensification for the sustainable design. So, thank you.