Chemical Process Intensification
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Lec 03
Strategies and domain-based techniques

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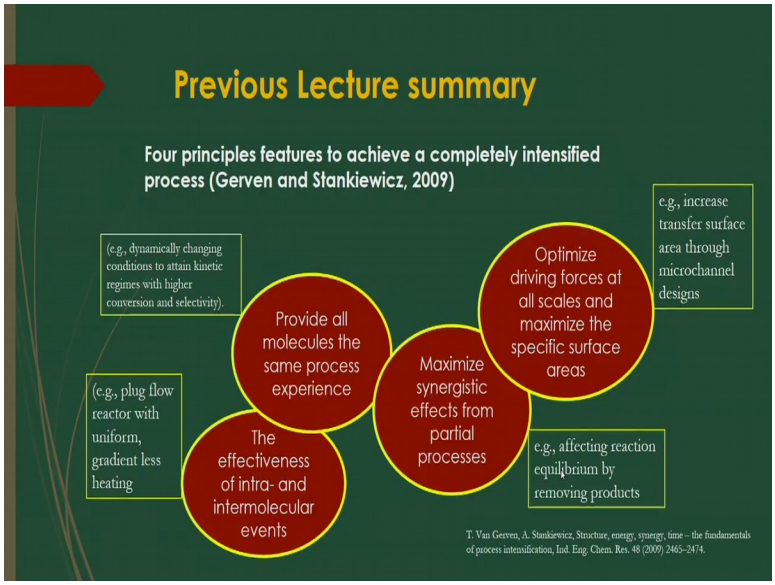

Welcome to Massive Open Online Course on Chemical Process Intensification. So, today's lecture will be on strategies and domain-based techniques under module 1 Introduction. So, in the previous lecture we have discussed something about the basic principles of the process intensification along with the perspective of process intensification

And we have discussed that generally for basic principles, as per Gerven and Stankiewicz, 2009 that the basic principles of the process intensification will be the effectiveness of the intra and intermolecular events and based on which that any chemical engineering process intensification starts, and it will starts from the molecular level that will give you some reaction mechanism and from which you get some products and after that all molecules will have the same process experience based on which that the direction of the process will go.

And after that basic principle of that process intensification is to maximize the synergetic effect from the partial processes of different chemical engineering processes. And then optimize the driving forces at all scales and maximize the specific surface areas based on which the intensification can be done for process chemical engineering process. And in that

case, you will see whenever we are getting different products after reactions and then you need to have to separate the products and byproducts from those mix of chemical reactions.

And for that several separation processes are actually employed to separate those chemical compounds based on the process intensification principles, all those compounds are being separated by different mechanism, by different processes by the process intensification. And in that case the effective surface area is one of the important phenomena because all the chemical processes actually, directly or indirectly related to the multi-phase flow processes.

So, in that case the more than one phases were taking place to take part in reactions and yield the different products. In that case, to separate those products you have to have the surface area between the phases. So, in that case, contact areas as well as its residence time in the reactors is main important feature or main important aspects by which you can optimize the driving forces based on which that compounds are being separated from one phase to another phase.

So, in that case different other, whatever that operating conditions will be governing those, you know, degree of driving forces for this mass transfer or separation processes. So, you can develop some equipment or device or develop some methods based on these criteria and optimize those process by these process principles. So, these are already been actually described in the previous lectures. Even some other, you know that basic features, that is most important aspect that is given by Gabriel Segovia Hernandez and Bonilla Petriciolet.

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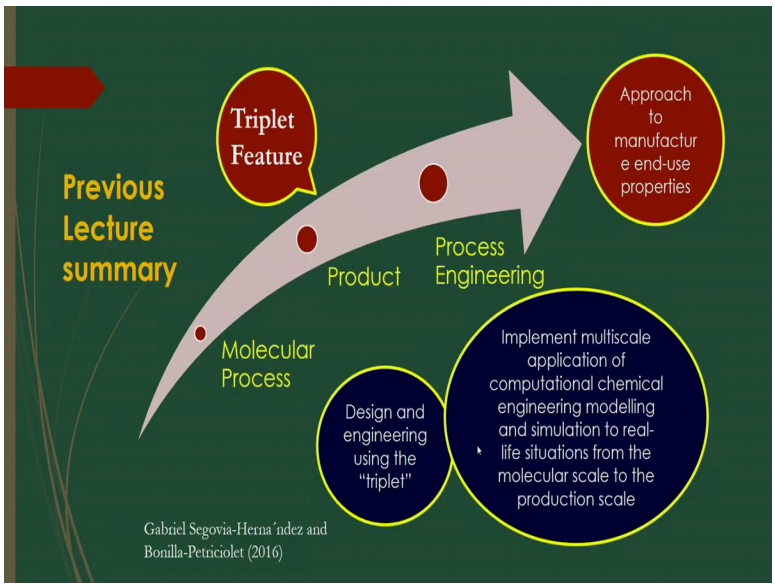

So, in that case, they have given that the principle of process intensification depends on three main features. It is referred by them as triplet feature. They have told these features as molecular process, product and process engineering. This molecular process means the reaction process in molecular level and then by this molecular process you can get the product and the product will be of course the mixture of different products and byproducts that is desired products and undesired products also.

Even unreactive products also would be there. So, after that to separate those products, you have to separate those products or byproducts based on some principles. So that is called process engineering. So, this process engineering is developed based on the mechanistic properties of these, or physical properties of the products and byproducts based on which how it can be separated.

Now there are different aspects of separation processes and intensification of those processes like, you know that this intensification can be done based on the physical process, based on the physical phenomena, based on the, you know that equipment what are used for that particular process. So, development of some equipments, some novel devices by which you can separate these products by this process engineering method.

Other phenomena like that, you can develop some methods, that conventional methods can be avoided to get intensified way to separate those products. Like sometimes you know that, to separate those products and byproducts you have to mix the phases in intensified way. Now there should not be back-mixing in the particular processes of the phases.

So, in that case you have to reduce that back-mixing. To reduce that back-mixing you have to develop some process, you have to develop some methods, you have to develop some devices so that there will be less back-mixing or high residence time there. So, this is the thing. And based on the process engineer then, you can have the final products with a certain degree of purity. So that is called approach to manufacturer end, that will use for commercial purpose.

And in that case implement of the multiscale application of computational chemical engineering model is also important because all those processes, how it has happened, how to predict those processes, what will be the yield and based on the operating conditions, what extent of product, what extent of the efficiency of the process can be obtained, that can be actually simulated or mathematically interpreted by some simulation process or mathematical expressions.

So that is why the implementation of this multiscale of applications of this process engineering for the process intensification you need to do the modeling and simulation of the processes. And those things, of course, based on this modeling simulation process, this design engineering, of course, will be actually progressed on, because all the design of this equipment or intensified devices that depends on the, you know that physical phenomena of the process inside that.

So before going to design you have to do the experiment in laboratory scale and simulate based on that laboratory scale data and scale up to higher commercial scale. So, this is the way that is triplet features that is given based on which you can intensify the process.

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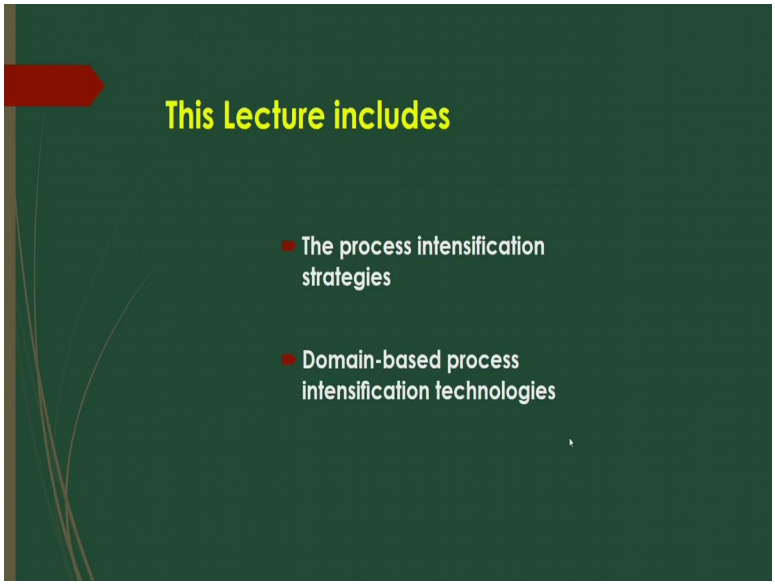

Now, in this lecture we will discuss something more about that process intensification. It is called strategies of process intensification. And also, what are the domain-based process intensification techniques are available, we will actually discuss here in this lecture.

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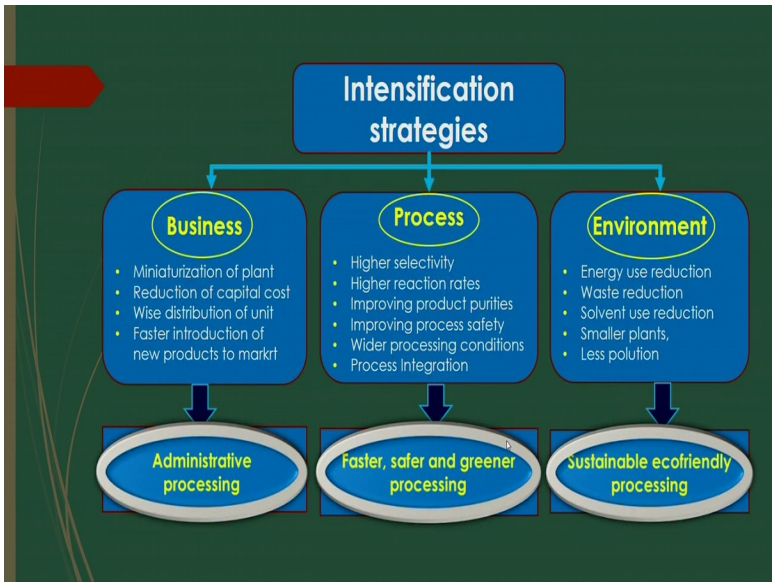

Now, see in this table that if we classify these strategies of the process intensification and we are having three strategies like one is business, another is process and then environment. In the business aspect, of course, the main strategies of this intensification is that you have to miniaturize the plant. That means you have to scale down the plant.

That is, you know that smaller size of plant will give you less consumption of energy, less consumption of cost, so in that case you have to have strategies of the miniaturization of the plant. And also, reduction of the capital costs what are by investment, that investment must be less based on this reduction of the capital cost by designing in such a way that the small-scale equipment should be designed in such way that it should be efficient and it should be given the same output as conventional processes.

Also, that is wise distribution of the unit, that is also one business strategy that whatever products is coming out from the, you know that process that you have to distribute it well, management throughout the unit and through different commercial hub so that the product should be wisely distributed and it would be well-managed and optimized prices of the output and faster introduction of the new products to market also.

You have to well-advertise in the market so that your new products, whatever it is coming that in the market, not that, nowadays that you know advertisement is the main important factor. That how you are actually selling the products. That you have lot of products but sometimes the consumers may not come to you because they do not know what type of

products and what extent of purity of your products that is to be actually advertised in the market so that the consumer can easily know your product based on your, what is that intensified way.

And then the process strategy is that, anyway your strategy should be in such a way that the selectivity should be high. So, you have to develop the process where high selectivity can be achieved. And also, the whatever reactions are being taken place in your process intensification way in chemical engineering or some other engineering processes that if it is some reaction oriented, then you have to increase the reaction rate.

And also, after reaction and you will get the product, that you have to separate those products in a certain degree of purity. So, you have to improve the product purities also improving the process safety whenever you are doing some process for producing some products, so you have to make some firsthand safety for that operation. So, it is also important. Now, safety not like that conventional way, you have to take measured intensified way of safety for that process operation.

And wider processing conditions also important there, you have to keep in mind that try to minimize that process condition because lot of conditions may sometimes interact to each other and they may hinder the process output there. So as much less as possible, that process conditions to be actually optimized there. And also, some processes that are coming with this less number of, you know that process conditions by integration of the process.

So you can integrate the process, you can conjugate more than one process in a single unit so that you can omit some, you can, you know that avoid some unwanted process conditions what happens in a particular process. So that is why the process integration is also one important strategy for process intensification. Then environment, this is one of the most important strategic features of that process intensification.

You have to intensify the process in such a way that your energy use should be less, your waste, whatever waste is coming from your process operation that should be reduced. And what are the solvents that you are using, that should be intensified solvents so that waste solvents should be less and smaller plants are one important aspect that you have to scale down of that process to get more output and also finally that less pollution.

This is the final goal whatever products are coming out, that should not be hazardous in nature that should not be making any pollution in the environment. That should not be any health problem in the society. So, in that way you have to intensify the process so that after output whatever coming after this process intensification where that will get less pollution in the environment. So, there are three strategies what we are actually dividing here.

One is administrative processing that is business purpose, another is faster, safer and greener processing, that should be like process higher selectivity, how can get the higher reaction rate, how can improve the process safety, how can reduce the wider processing conditions, how can we integrate the process to consume less energy and also less precautions to be taken during the operations.

And also, sustainable eco-friendly processing should be there, so that the less energy can be consumed, and less waste will be there in the environment and less chemicals to be used so that the hazardous materials will not be coming into the environment and also as smaller as possible you have to make these plants and also less pollution to be created. So, these are the basic strategies of the process intensification like business, process and environment.

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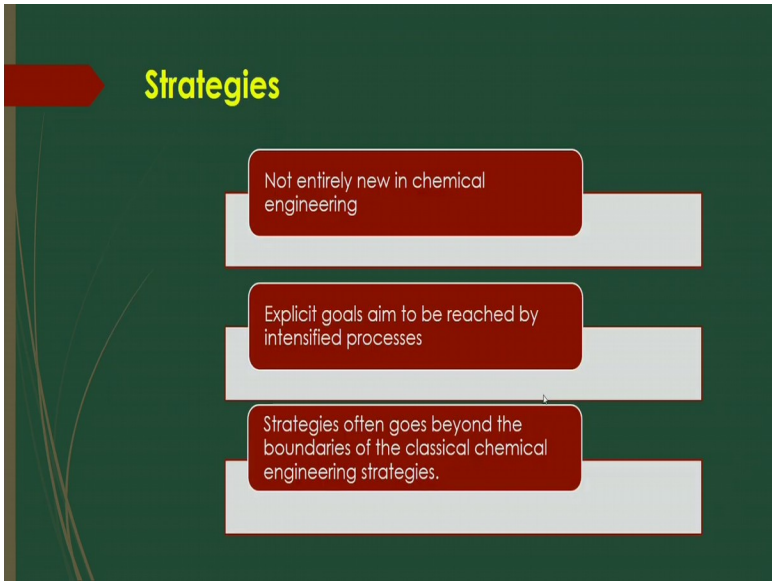

Now these are the, whatever strategies that we have told that these strategies actually not entirely new in chemical engineering, in chemical engineering, all chemical engineering process, all those strategies are actually taken care but nowadays since populations are being increased and pollution in the environment increased so you have to have some explicit goal to reach the clean environment by some process intensification way. And in that case, you

have to consider the chemical engineering process in some classical way so that you can get the less polluted environment in society.

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Now for that you know that our society has to face the challenges of that modifying the traditional industrial growth to a sustainable growth because our population is day by day increasing, to fulfill our demand in the society as well as the market whatever tells that, so we have to face lot of challenge to fulfill our goal to supply the products as per demands.

So, for that many strategical operations in different strategic sectors are taken, like water, energy, food, health etc. in different sectors, they have taken, they have actually developed different processes for the intensification of the process so that necessary transformations will take place consistently with the process intensification principles. So that is why the challenges to the sustainable growth is here to actually fulfill the demand of the society in our populated domain.

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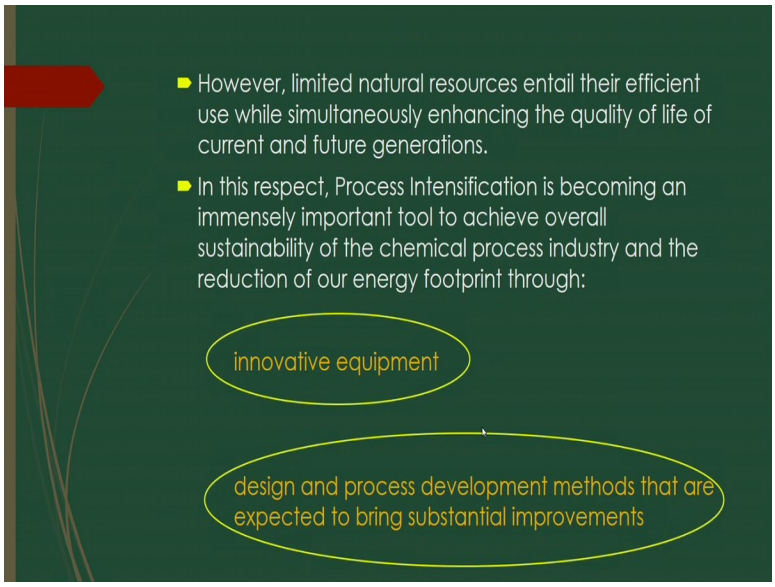

So however limited natural resources entail their efficient use while simultaneously enhancing the quality of the life of current and future generations we are of course bothered about that, that we have to give the better generations, we have to give, you know that quality of life to our future generations. So, in this respect we have to develop the process in such a way that it will become an immensely important tool to achieve overall sustainability of the chemical process industry and the reduction of our energy footprint through different basic features.

Now innovation of the equipment is one of the important features based on which that you can intensify the process and you can give the better products and more products in the society. Design and process development methods, that are expected to bring substantial improvements in the society. So, for the process intensification you have to design and develop the process in such way that you can have substantial improvements in process methodology, development of the equipment and sustainable growth for our society.

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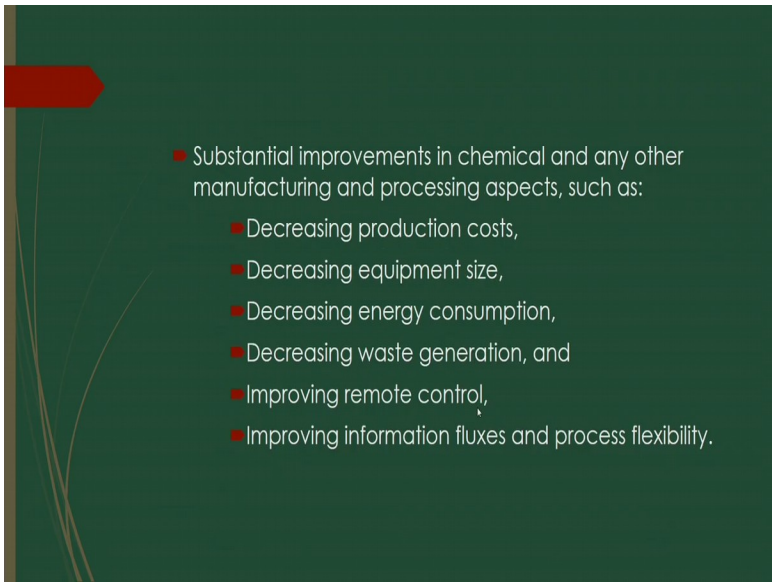

Also substantial improvements in chemical and any other manufacturing and processing aspects, that also very important tools and that depends on some factors like, you know that you have to decrease the production cost, you have to decrease the equipment size, you have to decrease the energy consumption, you have to decrease the waste generation which is coming out of the process and also improvement of the remote control and also improving information fluxes and process flexibility. So, these are the main tools by which you can, you know that improve chemical in other manufacturing process aspects there.

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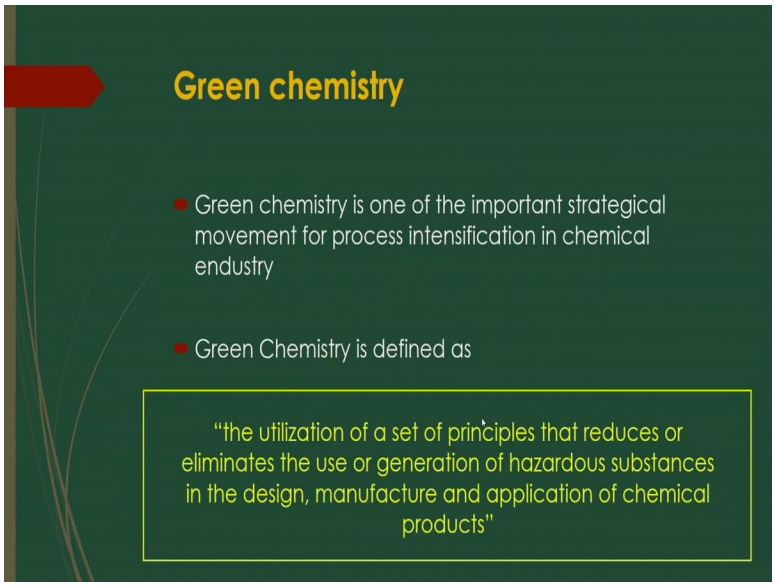

In this case or in this regard we have to say what in this regard of green chemistry where it is one of the important strategical movement for process intensification in chemical engineering or chemical industry where you will see the whatever chemical processes are being carried out, that should be in greenery way, that means less number of hazardous materials to be produced by this green process. So green chemistry is one of the important tools by which you can develop some process and based on which you can get the, you know some products which will be highest purity and also less environmental pollution.

So, in that case you have to use some solvent that will not be hazardous and 100 percent use of solvent should be there. And whatever byproducts will be coming out, that should be, you know that, again to be converted to some other useful products in the society so that the hazardous material as a byproduct that should be converted to other products and to be useful for other uses.

So, in that way you can converting these hazardous materials to other useful products so that is why whatever green technology that should be used, you have to consider some, you know that efficient solvents where the less waste of hazardous materials are coming out in the products. So green chemistry is defined as the utilization of set of principles that reduces or eliminates the use of generation of hazardous substances in the design, manufacture and application of chemical products.

So, the main aspect is to that develop the process in such a way that whatever reactants, whatever materials to be used for that intensification, process intensification for this greenery way, that green chemistry should be followed. So green chemistry that means synthesis of the chemicals in such a way that less number of hazardous materials to be produced during the synthesis process.

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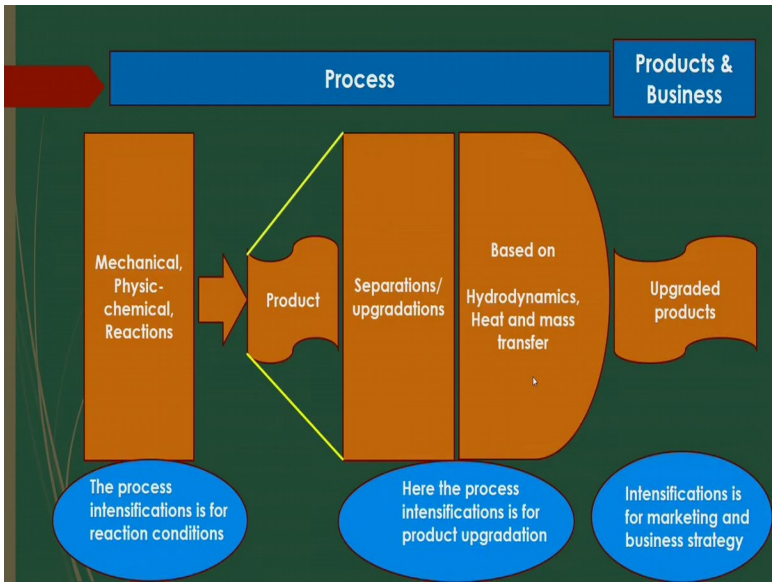

And here you will see whatever process we are talking about for the process intensification and to get these products and then after business you will see there are different processes in mechanical process, physicochemical process, reaction processes, those processes may simultaneously occur, or integrated way that may happen or individually may happen. Some mechanical processes that may not actually integrate with the reactions there.

Some processes totally, you know that mechanical means yes, suppose you want to reduce the size of catalyst particles there to get the more surface area so that the reactions should be, you know intensified. Or some processes you know like, separation, physical separation processes. In that case particle size is very important. So, fluidization processes in chemical engineering processes you will see they are the, size of particle matters. So, in that case mechanical processes where you will see the size reduction is needed. So, in that case you have to intensify that size reducing process.

Some other mechanical process for physical separation is by membrane separation. You have to develop some membrane, that different types of membrane ultra, even nano, you know that meso scale level, even different types of materials, you know ceramic membranes, polymeric membranes. There are different membranes. So those are mechanical way to separate that different products and byproducts.

So physicochemical process for absorption there you see some, you know suppose separation of Sulphur dioxide or nitrogen dioxide, or carbon dioxide in a liquid. So, in that case main

process is that it depends on the physical properties of the system, like what type of solvents, what are the properties of the solvents that you are using for absorption of carbon dioxide from the atmosphere or NOx, separation of NOx in amine solution or some other, you know solvent known other, you know the solvents.

So, you have to develop the solvents. You have to develop the, you know that interfacial area to; you know separate those gases into liquid. So, these are called physicochemical processes. Even reactive processes like, you know reactive distillation, you know extractive, extraction, you know reactive extraction, even reaction processes to synthesis the different products and byproducts from a natural source, that is reaction.

So, after getting these different products by this mechanical, physicochemical or you know reaction processes you will get different products. So those products to be separated by different processes. Now separation processes or it is called upgradation processes, you have to separate different products and byproducts in different uses. And based on hydrodynamics, heat and mass transfer that separation or upgradation to be actually depending on.

Because, you know whatever you know reactions or whatever separation processes are being carried out in a particular reactor or in a column or in a devices how this device is being operated, there are different variables that actually governs this processes like suppose separation efficiency or yield of the separations or suppose mass transfer, basically main term is mass transfer, heat transfer that mass transfer or heat transfer that depends on the operating conditions there.

And main parameters based on which that mass transfer or heat transfer depends on it is called mass transfer coefficient or heat transfer coefficient. Even these other parameters in hydrodynamics like, you know if you are working with or your operation of the process is with suppose, different phases like, you know gas and liquid, gas, liquid, solid in a particular unit like fluidization operation, there gas-solid fluidization like, you know combustion of coal to produce different types of gaseous products.

Even, you know Fisher-Tropsh synthesis, from the natural gases, how these natural gases or you know that synthesized gases to be converted into different, you know gasoline, even you know other different LPG, or other different gaseous products even some other petroleum products that are being produced.

So, in that case the process that is performance that depends on different operating variables that operating variables are like this. You know that some are called dynamic variables. Dynamic variables are called you know that flow rate when velocity of the fluid inside the reactor even you know that some holdup of the phases inside the reactor. Even some geometric variables, you can you know intensify the process based on the, you know that operating variables like it is called geometric variables.

Like you can change the diameter of the column, you can change the length of the column, you can reduce the size of the catalyst what are being used for particular chemical reactions as a catalyst and you can, you know change the, what is that distributor through which that gas or liquid is being distributed or spraying to get the more interfacial area of the phases or interfaces through which mass transfer happens, or heat transfer happens.

So, these geometric variables also govern this process performance there. Other like physical properties also important variables like if you are using different types of chemicals, different solvents, different reactants, you will have different physical properties of those reactants or you know liquids or fluids that you are using. Like physical properties like density, viscosity, surface tension, all those will vary and all those properties will actually change the process performance in your particular operation.

So, this heat and mass transfer process are involved in separation and upgradation process and this heat and mass transfer, that will actually be depending on the hydrodynamics that means how fluids are being actually behaving inside the reactor, whether it will be circulating well or it will be homogenization or whether it will be heterogeneously actually mixing inside the bed, that depends on the process output. So, you can intensify that, you know that process based on this hydrodynamics, heat and mass transfer phenomena.

And after getting the products and byproducts based on this upgradation and process intensification for these you have to anyway market these products for business purpose. So, you have to make a strategy for that business, how actually consumer can get those products easily and also aware of those products in the market, whether it will be acceptable range of degree of purity or not, that should be actually highlighted in business strategies and also advertisement to be given in the market so that, that your degree of purity of the products in a certain level.

So that is business strategy how to actually sell the products in the market easily and how to aware the peoples that these products will be good or not. That should be actually considered. So, these are the strategies that some process intensification is for reaction conditions where this mechanical, physicochemical and reactions are being actually considered. And process where you know that intensification is for product upgradation, there separation upgradation based on hydrodynamics, heat and mass transfer to be considered and intensification should be based on the marketing and business strategy also.

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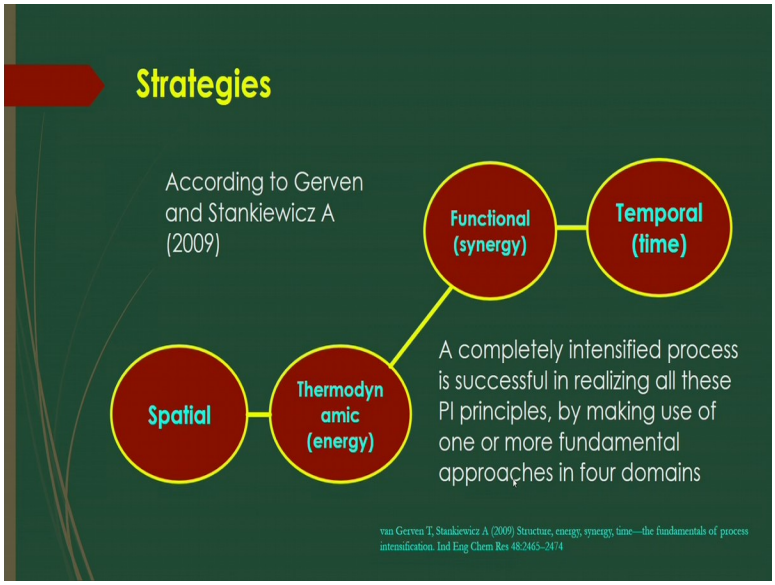

Now according to Gerven and Stankiewicz A, 2009, they told that process intensification strategy should be the four way like you know that the sum should be spatial. That means here less, you know the space should be, you know used. That means here macro to micro you know, plant should be developed and their thermodynamic condition to be considered there, that means less energy to be consumed so in a particular process suppose higher pressure drop is there.

So, you have to reduce that pressure drop because higher pressure drop whenever in a particular reactor that to distribute the fluids more energy to be consumed for uniformly distribute of this, you know that fluids. So in that case energy consumption will be high so you have to keep in mind that how to intensify those process by less consumption of energy and by, you know that having less, you know that pressure drop inside the reactor and also as much as possible that the reaction should be, you know that atmospheric condition so that

extra energy, extra heat should not be supplied therefore you know that process output. So, the energy is one important point for this process intensification strategy.

Also, another is functional, of course, different you know condition to be considered here, functional whether it will be, you know that based on flow behavior or whether it should be based on other physical properties of the system or not, how it can be actually processed based on the physical properties. That means less you know viscous fluids to be used, less hazardous materials to be used when less consumption of the solvent will give you higher output so you have to synthesize the solvent or materials in such a way that it will give you the higher proficiency of the product output based on these material properties.

Temporal like you have to, you know that use less time for your products, you know for your production, because in that case if you are consuming higher time so you may, you know consume more energy, more you know that capital cost should be required and also in a particular process, chemical engineering process, in that case for higher residence times sometimes it may hinder the process output. So sometimes some particular processes you need to have less residence time of the fluid.

For those processes you have to design the process equipment in such a way that for higher residence time, for longer time of the fluid element to be staying inside the column. Like you know that for getting more residence time I told that earlier that downflow column, suppose gas is to be supplied from the top to bottom in a reactor against its buoyancy then you can get the more residence time of the gas bubbles for the mass transfer through the interface.

So, in that case downflow movement of the bubbles or inverse bubbly flow is one important aspect of process intensification to get the more residence time of that bubble or fluid. And so according to Gerven and Stankiewicz that the completely intensified process is successful in realizing all these process intensification principles by making use one or more fundamental approaches in such four domains.

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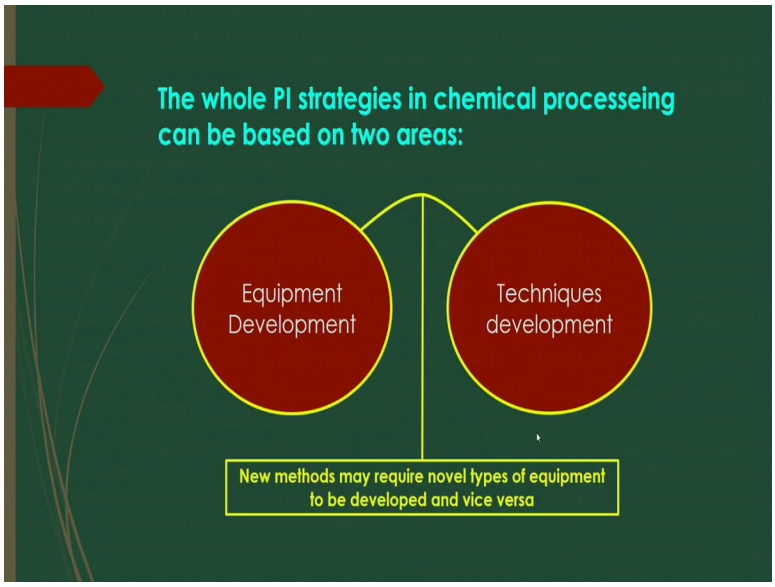

And the whole process intensification strategies in chemical processing can be based on two areas. They are equipment development and techniques development. Whatever processes that we have actually discussed, all those processes you can concise in a two-way like you know the equipment development is also one important because whatever reactors are being developed, so reactors should be intensified way so that your reaction mechanism should be, you know intensified.

And also, techniques development, different techniques should be, conventional techniques should be avoided because in that case higher energy is being consumed, as we know. So, you have to develop some techniques where the less consumption of energy will be there. Even greenery way that you have to develop the synthesis process so that you can get the less hazardous material which will be used for different products for our daily use. New methods may require novel type of equipments which is to be developed and vice versa.

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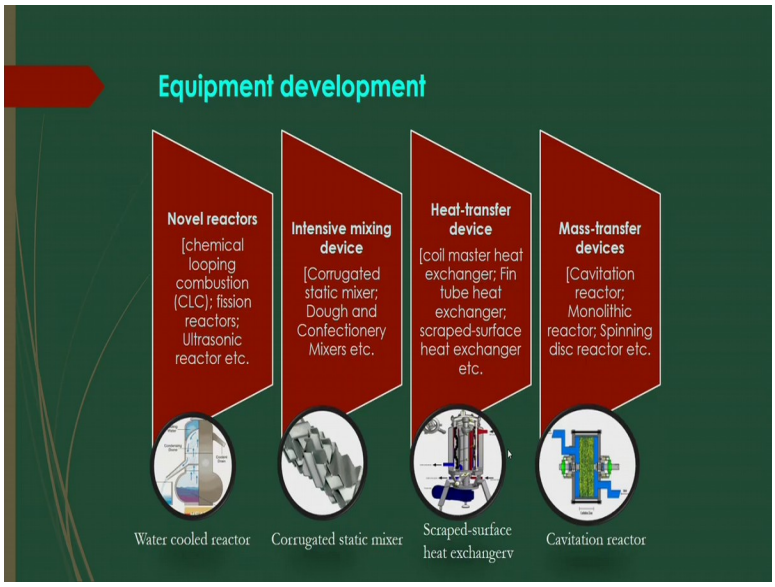

Now equipment development, for that you have to consider some novel reactors like chemical looping combustion reactor, fission reactor, ultrasonic reactors based on different, you know that process intensification techniques you can develop, the novel reactors are there. There are several reactors are available nowadays for the process intensification and also intensive mixing device to be actually developed.

Sometimes you have to have the homogenization of the fluid mixer in the reactor so you have to mix the fluid in intensified way. So, you have to develop some mixing device where gas-liquid or gas-liquid-solid or solid or gas to be mixed in the reactor. Like you know sometimes static mixer are being used where channel-based mixer sometimes it is considered for gas-liquid mixer.

Even in fluidization, instead of packed bed you can mix the solid gas more intensified way just by, you know that circulating that gas inside the bed. So, this is called circulating fluidized bed. So, in that case you can mix that solid in homogenous manner based on different flow patterns. So other intensified device like corrugated static mixer, dough and confectionery mixers, these are some examples of intensified equipment or mixing device were commercially being used.

Heat transfer device like you know that coil master heat exchanger, if you are using only simple straight tube for heat transfer like to, you know that heat the liquid you have to supply

another liquid or gases that is, may be cool or heated, so double pipe exchangers are there, shell and tube heat exchangers are there. Even fin tube heat exchangers are there.

Now coil master heat exchanger important because you know to, you have to place that heat exchanger in a very small space so in that case sometimes the tube should be made, you know the curve shaped or helical shaped way so it is called coil shaped. So, you have to supply that liquid through the coil, hot water through the coil in a less space that is number of turns that depends on how actually intensified way that heat transfer can be done by this coil.

And also fin tube heat exchanger, they are just increasing the surface area to improve the heat transfer phenomena, these types of heat exchanger are being developed and also separated surface heat exchanger also. You know that channel-based heat transfer equipment are being developed nowadays. Micro channel based, they are n number of channels, micro channels through which liquids will be supplied or some solvents or you know that refrigerant to be supplied so that the other liquids which are to be cooled down can be easily done.

So these are called micro channel based, micro channel based heat exchanger equipment. So as a process intensification for heat transfer, the heat transfer devices are being developed based on the surface area. Mass transfer devices also are being developed based on the surface area.

Even cavitation reactor where you will see that some gas bubbles to be produced when, by sono, or you can say that ultrasonic way that bubbles will be produced so that it will be, its size will be more, you know that finer, that is called microbubble when nowadays nano bubbles are also being produced for getting, that is more mass transfer separation of the, you know some particles, you know micro bubbles are being used in, you know mineral industries for separation of fine particles from the solution.

Even these microbubbles are being used for arsenic removal in advanced oxidation process like ozonation process. Even microbubbles are being used for medical industry, for gene delivery, drag delivery; all those purposes these microbubbles and nano bubbles are being used. So, these cavitation reactors are being developed in such way that where micron size bubbles can be developed by this ultrasonic mechanism.

Monolithic reactor is also one type of reactor where some materials are being synthesized there and, in that case, nano materials to be developed and based on that nano material

properties that intensification of the process are being done. And spinning disk reactor also, nowadays are coming that separation as well as reaction both happen simultaneously in integrated way. So, in this case, spinning disk reactor is also one important intensified equipment for mass transfer. So, the process intensifications are being actually done in different way so equipment development is one of the important aspects for that.

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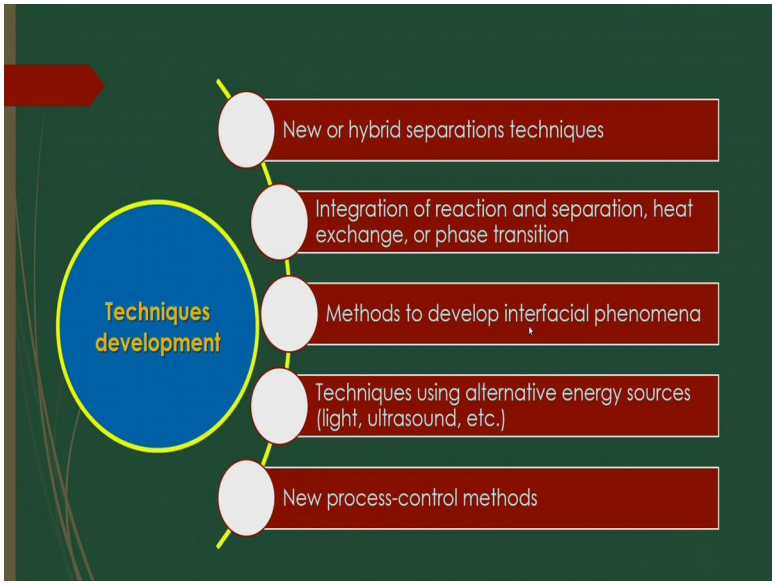

Main strategy for these techniques' development is to develop the new and hybrid separation techniques, integration of the reaction and separation, heat exchange or phase transition, even some methods to be developed where interfacial phenomena works. And also, techniques that should be developed where alternative energy sources to be used, like light, ultrasound, etc. or you can say, you know that some other magnetic field where this alternative energy is being used to intensify the process. New process control method of course to be developed for this process intensification.

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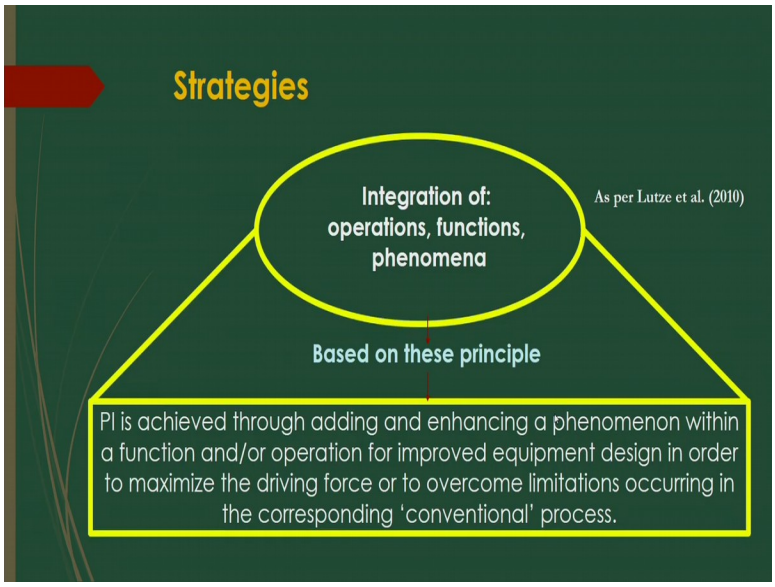

So, we can even classify these strategies of this chemical engineering process like that integration of the operations, functions and phenomena are three components by which you can intensify the process by integrating the different processes. Based on these principles, the process intensification is achieved through adding and enhancing a phenomenon within a function and or operation for improved equipment design in order to maximize the driving force or to overcome limitations that occurs in the corresponding conventional processes.

And targeted enhancement of a phenomena of a given operation, that also influences the process intensification to get through improved use of, you know respective phenomena or functions to overcome limitations that occur in a given conventional operation.

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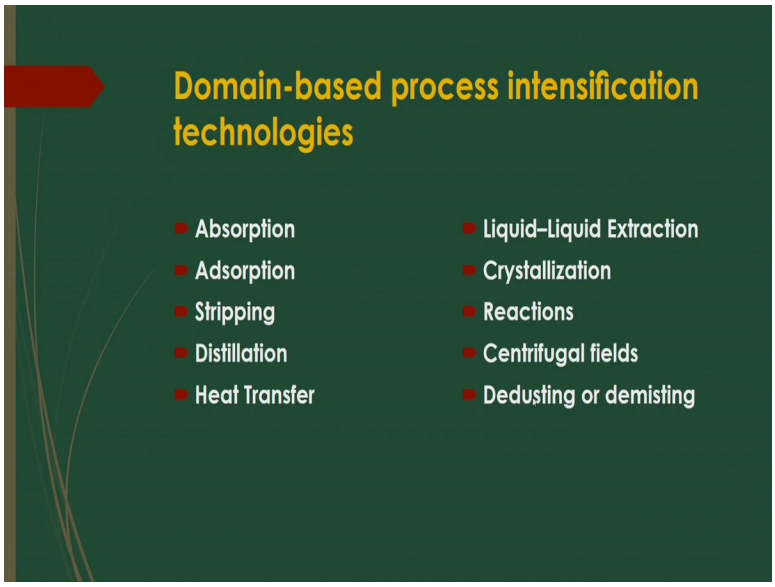

Some domain-based process intensification techniques are also there in chemical engineering process. Those are very important like absorption, adsorption, stripping, distillation, heat transfer, liquid-liquid extraction, crystallization, reactions, centrifugal fields and dedusting or demisting. Some other operations like fluidization, even bubbling phenomena. So, these are the techniques based on which you can intensify the process.

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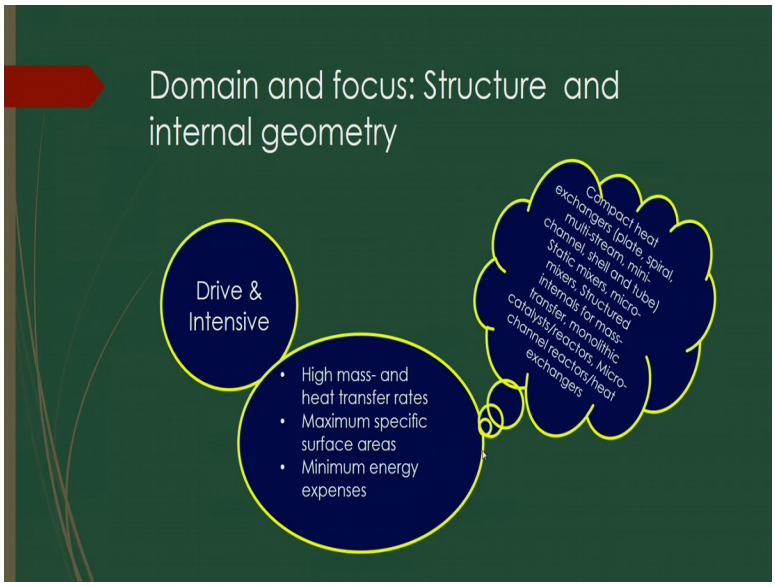

And for that some focus to be, of course, to be considered on that structure and the internal geometry like this, you know that, to get the high mass and heat transfer rates, maximum

specific surface area and minimum energy expenses. To have that you have to drive that process in such way that you can get the high mass transfer and heat transfer rates there.

And also, this happens in generally some common equipments whatever available in the market like compact heat exchangers, plate and spiral multi-streams, mini-channel, shell and tube heat exchanger where static mixers sometimes being used for this mass transfer and also structured packing material also are being used for getting more contact between the phases so that that heat and mass transfer to be more.

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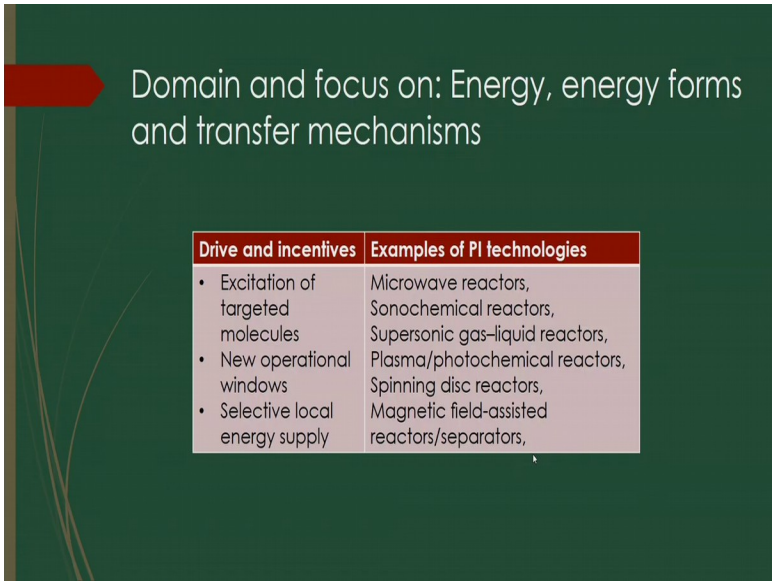

Even you know that some energy and energy forms and mechanism of those are considered for that heat and mass transfer there. Like excitation of the targeted molecules sometimes is being done for reactions before going to its main processes. And also new operational windows, selective local energy supplies also to be considered for that intensified way to get the process intensification.

Like you know the microwave reactors, sono-chemical reactors, there some magnetic field assisted reactors are there, spinning disk reactors are there. There you know that some reactors or separators are to be developed based on this; you know that new operational window and selective local entropy supply or energy supply there. So, there energy and the form of energy and based on which how mass transfer and heat transfer will happen, so based on which the process intensification can be done.

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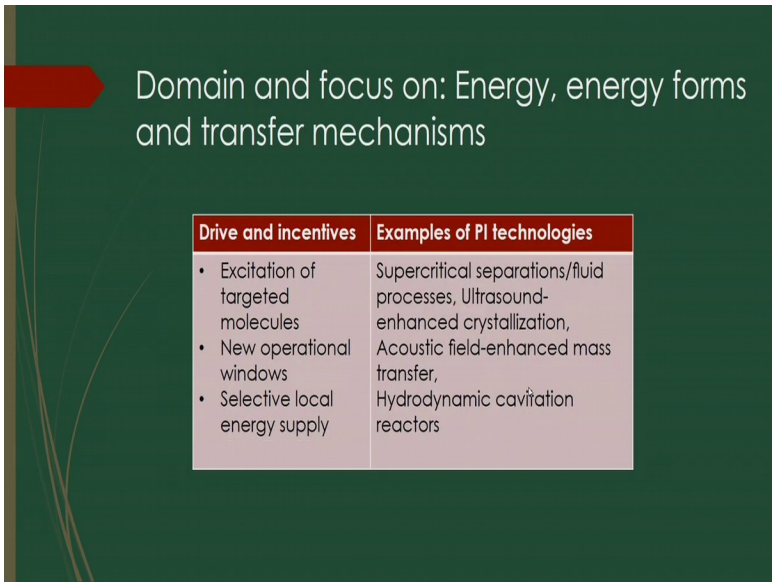

Even some other important operations like supercritical separations, fluid extraction, even fluid-fluid you know that solvent extraction, ultrasound enhanced crystallization, even hydrodynamic cavitation reactions there where this process intensification is being done based on this energy and transfer mechanism of that.

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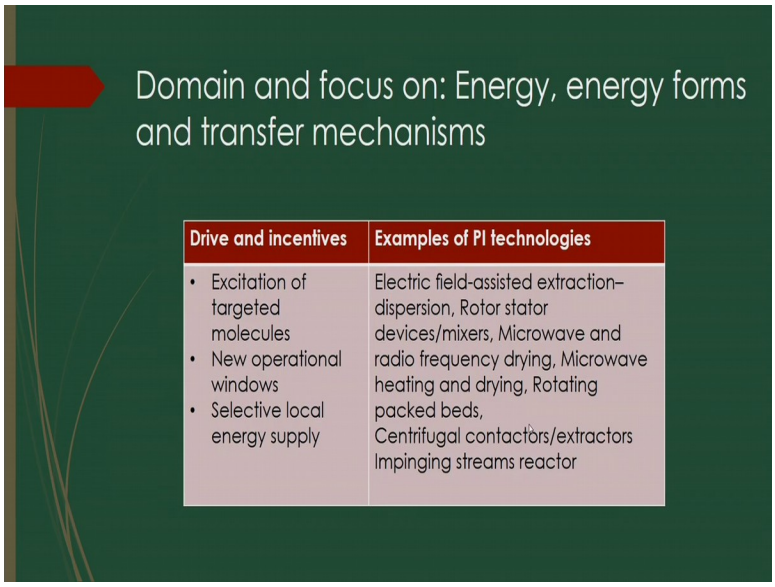

Even some other electric field assisted extraction process, dispersion, rotor stator devices, mixers, microwave and radio frequency, drying microwave, even heating and drying, rotating packed bed, centrifugal contractor and extractor impinging, stream reactors are also being developed based on this energy and transfer mechanism.

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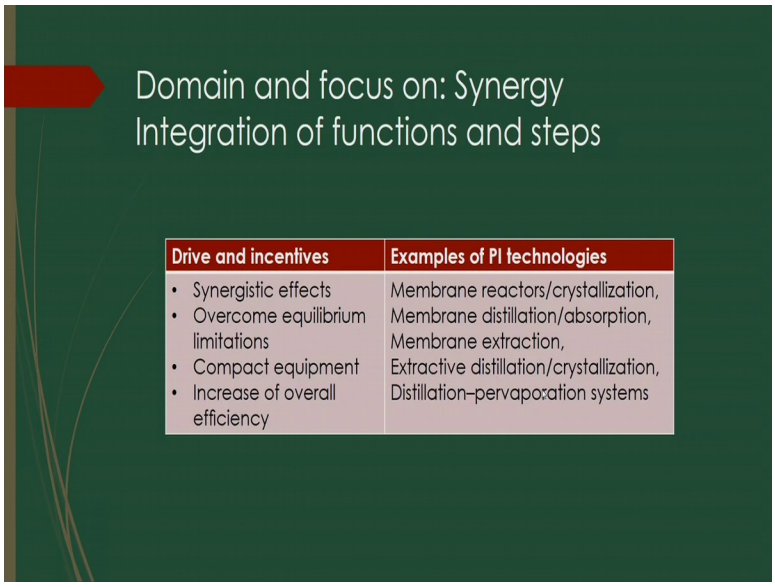

And some other mechanism like that drive and incentives like synergetic effect, overcome equilibrium limitations, compact equipment, increase of overall efficiency there, like membrane reactors, crystallization, membrane extraction, even distillation pervaporation systems are some common examples of intensified process in chemical engineering process.

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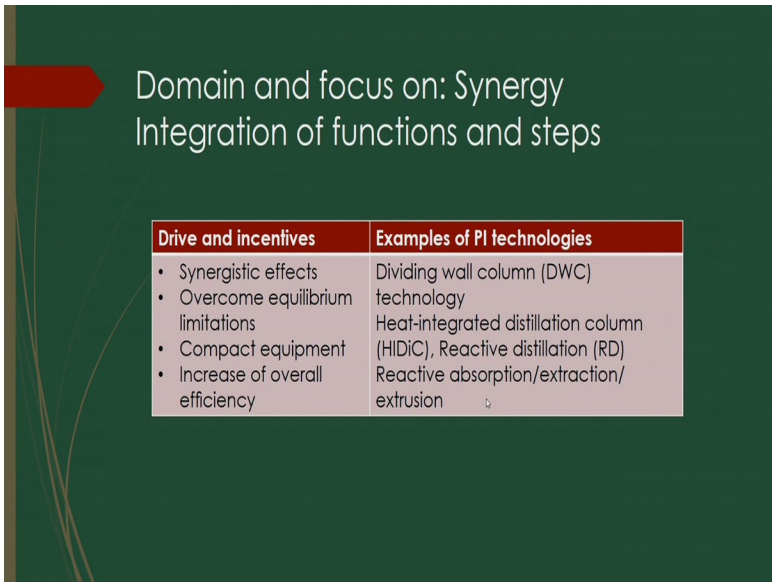

Dividing wall column, technology is also important, heat integrated distillation column are being used in the present days, reactive distillation where conventional, only one simple operation in distillation are not being done nowadays. So integrated dual like reaction as well

as distillation parallelly will happen in a single reactor. So, it is called reactive distillation. Reactive absorption and extraction both will be simultaneously occurs in a particular reactor.

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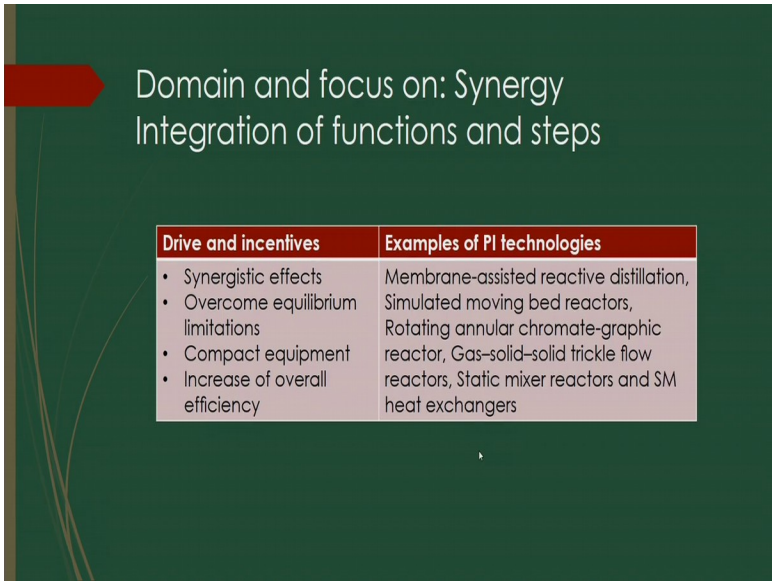

Even membrane-assisted reactive distillation sometimes, after reactions you have to separate those products. So, you have to use some membrane. So, membrane-assisted reactive distillation is a conjugated unit or you can say, integrated unit where this process intensification is being done.

Even some other process like, you know that gas-solid-solid trickle flow reactors in downflow systems, they are mostly in petroleum industry they are using this gas-solid-solid trickle bed reactors for crack catalytic cracking and other several petroleum products to obtain in a particular, this trickle bed reactor.

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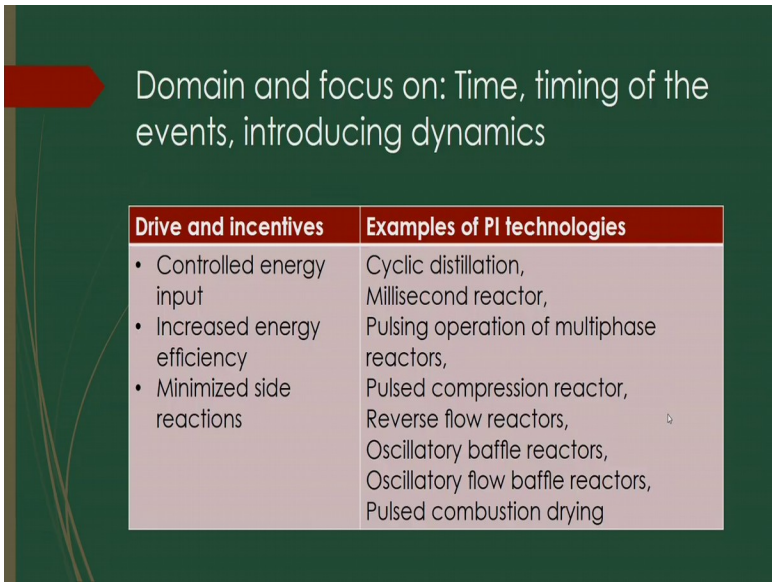

Controlled energy input is also, one important, you know that incentive strategies for, you know chemical engineering processes like cyclic distillation, millisecond reactors there even pulsing operation of the multiphase reactors are nowadays happened because to get the homogenization of the phases, pulsing operation gives the proficient operation in that particular packed operations. Reverse flow reactors, oscillatory baffle reactors are being used for intensified mixing in the fluid in a particular reactor to get the better yield in the chemical engineering processes.

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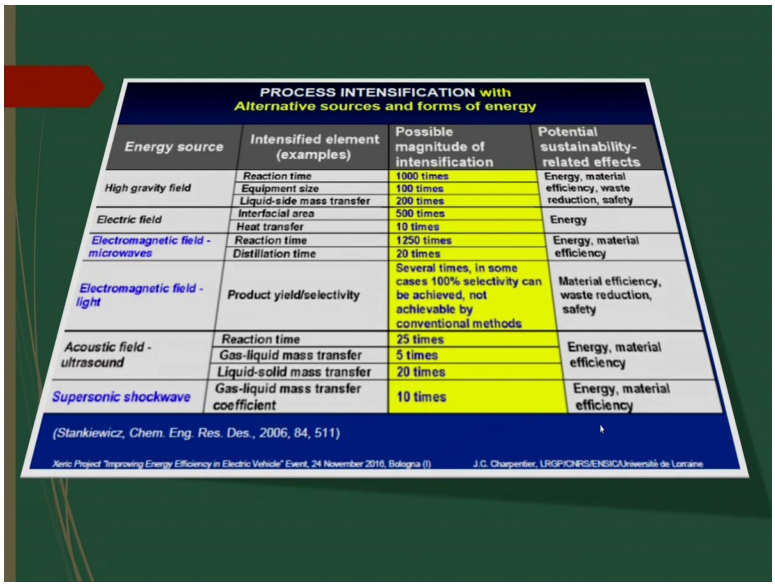

So, there are several process intensifications with alternative sources and forms of energy that are being here given, so high gravity field, electric field, electromagnetic field, microwave even electromagnetic field light, acoustic field ultrasound, supersonic shock waves. So, to use those energy incentives, you know that process, the chemical engineering process are going ahead based on this strategy that you have to develop some process and to get the, you know that magnified way of intensification like you know that reaction time.

You know equipment size, liquid-side mass transfer, gas-side mass transfer interfacial area, heat transfer reaction time, distillation time, you have to magnify this process output there. So different strategies that we have considered here in this lecture, I think we have now considered that what type of strategies to be considered for the process intensification. It will be helpful for your, you know the process design so thank you for this lecture.

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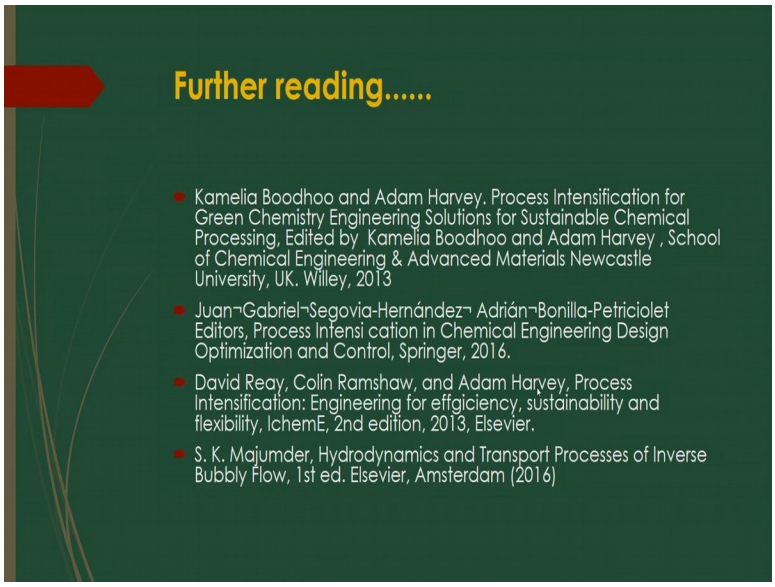

I would suggest you to, for further reading of these books for further information on these process strategies for process intensification, thank you.