Chemical Process Intensification
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History, Philosophy and Concept

Welcome to Massive Open Online Course on Chemical Process Intensification. So, this is introduction about the chemical process intensification. As you know that in our daily life, there are several products that we are getting from market. So, those products are actually being produced based on different processes. Those process may be of chemical engineering process, mechanical engineering process or some products that are directly and indirectly related to the biochemical engineering process.

And all those processes have some pros and cons based on their performance. Now, in that case you will see that some process which are developed to produce these different types of products, may be different, you know that disadvantages based on its, you know that product output, even the mechanism of the process because of which more energy is required to produce.

We will see some of the process that requires, you know that more, you know policy based and so in that case you have to have the output of the process that is, you know that mass of acceptable in range. And those process may not be actually eco-friendly and not sustainable in that case.

There are several processes those are being actually performed without actually considering the environmental policy. Those are considered that is not actually sustainable in process. Those process may not be lasting for several years. You know that, because of some environmental effect on social families so that those process may not be acceptable further for consideration of producing different products.

So, in that aspect now question is coming, then how to actually we produce those products based on some sustainable process techniques. And those techniques will be considered in such a way that, or designed in such a way that we can get eco-friendly and sustainable process and also the development of the social impact on that particular aspect.

So, let us first consider here one example how that process can be intensified based on its some disadvantages or cons. Let us see here there is a process to produce or suppose remove

the carbon dioxide gas from the atmosphere. And earlier stage you will see there will be a transfer of carbon dioxide from the atmosphere through the liquid medium. That process was followed.

Now, this process like you know that whenever gas is supplied through the liquid medium you have to produce some surface area. Now, that surface area may not be intensive as for its, what is that, output that is the removal efficiency. Like suppose when carbon dioxide gas is supplied from the bottom of a column in the core region where as in the wall of the column if liquid is supplied or flowing downward adjacent to the wall.

So, in that case you will see the gas and liquid there will be interfacial area. So that interfacial area will be actually main governing factor for the transfer of carbon dioxide gas or the gas to the liquid medium through the interface. Now, this is, that is very old process. In that case you may not get that much of intensified, that much of interfacial area to transfer this carbon dioxide to the liquid medium.

Now, later on you will see as a process intensification how to produce more surface area so that we can get more transfer of the carbon dioxide from this gaseous mixture to the liquid phase. So, based on which there is a, you know design of bubble column reactor. So, in that case you will see that whenever gas is supplied in the liquid medium as a dispersed phase of bubbles you will see there are various, there are, you know that sure more bubbles will be produced and producing interfacial area instead of simple just contacting of gas and liquid in a column.

And in that case, you will see whenever gas is dispersed from the distributor as a dispersed phase of bubbles in the liquid phase you will see there are n number of bubbles. There were huge number of bubbles will be produced. Now, so whatever volume of gas is supplied through the distributor the bubbles will be more. So, more bubbles will produce more interfacial area. So, in that case more mass transfer, that means more carbon dioxide gas will be transferred from the atmosphere to the liquid.

Now, if I say that other process, there will be suppose extraction process, liquid-liquid extraction. Suppose if you want to, if you want to remove some, you know propionic acid from the liquid where, in textile industry even other some industry where propionic acid is coming out, that you have to actually remove those propionic acid. Now, you have to extract that propionic acid from the liquid by some other organic liquid.

Like if you use some decanol, that decanol is actually immiscible in water. So, in that case if you produce decanol droplet, only decanol droplet that produce that surface area. Through the surface area that propionic acid will be transferred from that liquid phase to the decanol. So, this is the process by which you can intensify the mass transfer or you can say that the extraction process based on this concept.

There are several other concepts are available also to intensify the process nowadays. Those are actually carried out. Even some commercialization process also they are based on which they are doing research to get more intensified process and getting more intensified way of products by sustainable development. So, in this lecture let us start here with some history, brief history and some philosophy and the concept of the process intensification.

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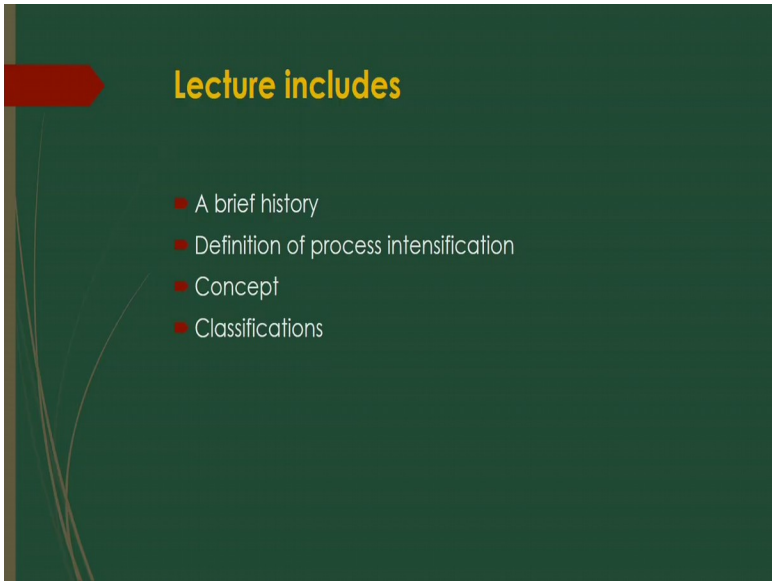

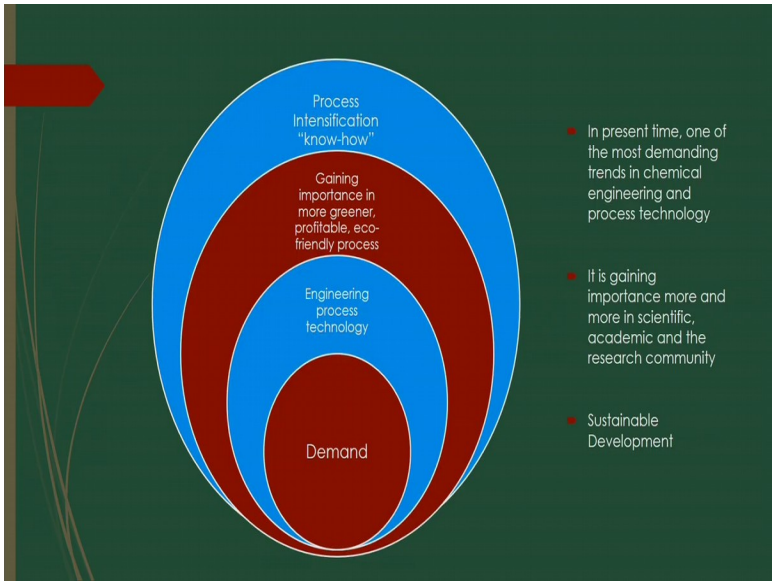

So, if we consider that in the early stage there, what exactly, that why that process intensification term has come here, because their huge demand to get the more products in the society and for which there will be certain technology that the product is coming. Now if you intensify that technology you can get more products and to fulfill that more demand in that case. So, in that case you have to develop the, or design the process in sustainable way so that you can get more products in the market with intensified way and also by consuming less energy and eco-friendly in the society. And that is why this process intensification actually are gaining importance in greener and more profitable and eco-friendly process in the industry.

So, in that case you have to know what will be the different methods and how to do that intensification. There are several ways to do the intensification like you know that in industry generally nowadays are being done for just reducing the, you know that process equipment, even reducing the, you know that energy, by reducing the, you know that time, that is very less time, how can, within a very less time you can get more products also. That is one way. And other aspects like, in that case, you know that space is very important here. Now macro to micro, then nano is coming.

Even development of different, you know catalysts or materials in the market by process intensification process from macro to nano and getting more, you know process development in sustainable way. So, these are the main things. So, in present time you can say one of the most demanding trends in chemical engineering and process technology for this process

intensification and by which you can get the eco-friendly and sustainable process to develop more greener product.

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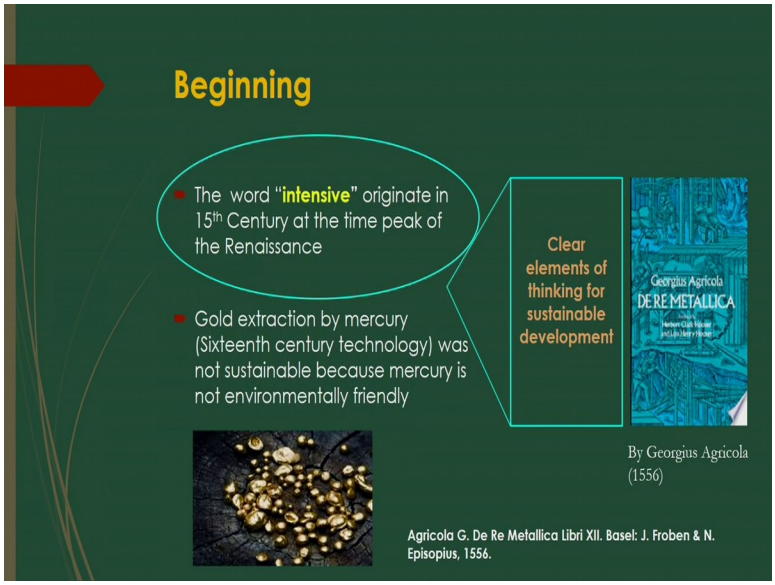

Now, let us see the beginning of that process here. The word that intensive actually first originate in the fifteenth century at the earlier stage, that the time of peak of, you know that Renaissance in fifteenth century. So, in that period actually Georgius Agricola actually published one book and where it actually, it was rich in description of different metallurgical process and he described the old process of metallurgy by which that they can extract different materials from you know that nature material or ores that is available.

So, you know that is not eco-friendly that, those process like gold extraction by mercury. So that mercury process everybody knows that this process of extraction of gold by mercury is not ecofriendly. And it is not being now used in the present technology to produce this gold from the ore by this mercury. And for that there are several ways now intensify those process to extract that gold from the ore.

And from then onward, that is 19 centuries, you know that in 1556, from that book actually the word is coming intensive and Georgius Agricola, he has explained that how to actually intensify the process of different chemical engineering, mining process by which you can get the product in sustainable way and also ecofriendly with consuming less energy there. So, the concept is coming from that period only.

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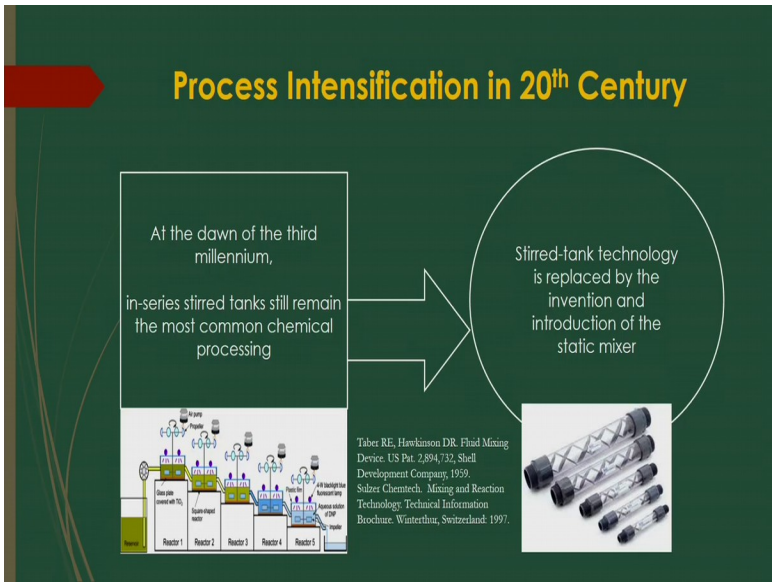

After that you know that dawn of the third millennium. At that time, you will see for the chemical engineering processing, main heart of the chemical engineering processing, to mix the two fluids or more than two fluids to get the reaction in presence of catalyst and getting a product. So, in that case you will see it was required to mix the fluids to get that reaction at a particular temperature and pressure. So, in that case they have used some series of reactor that is called stirred tank reactor.

So, in that case some mechanical device was used to actually mix the fluids to actually do that reaction. So, for continuous operation they have used that series of stirred tank reactor to operate those process for producing that product. And after that what happened they have realized that there is a mixing though it will intensify the, that is reaction process but there is disadvantage is that you know sometimes it will hinder the process yield because of back mixing.

So, based on that concept later on some intensification idea has come that how to reduce that big back mixing. So, to produce that plug flow model so that the molecules that is fluid molecules will not get, that is back-mixed with the initial molecules there which is supplied. So that concept is developed to produce that plug flow in a channel and that channel, if we are using that larger channel that will not be effective because again there will be a radial distribution of the fluid particle and because of which that yield may be reduced.

So, they have actually just converted that larger channels to narrow channel, narrow channels to the then micro channels, micro channels to the then you know that, nano channel now. Now to get that plug flow in the channel you will see that only there will be a contact of that fluid, fluid in the narrow channels and getting the more interfacial area and also you know that for continuous operation it will take even less time to get the faster reactions there.

So, they have actually tried to replace that stirred tank to the, you know that micro channel reactor that is called micro reactor sometimes it is represented. And later on, what happened, they have also other idea like you know that static mixer, how to mix that, you know the fluid in the static way. Like in the inlet and outlet there would be no back mixing of that fluid by the static mixer.

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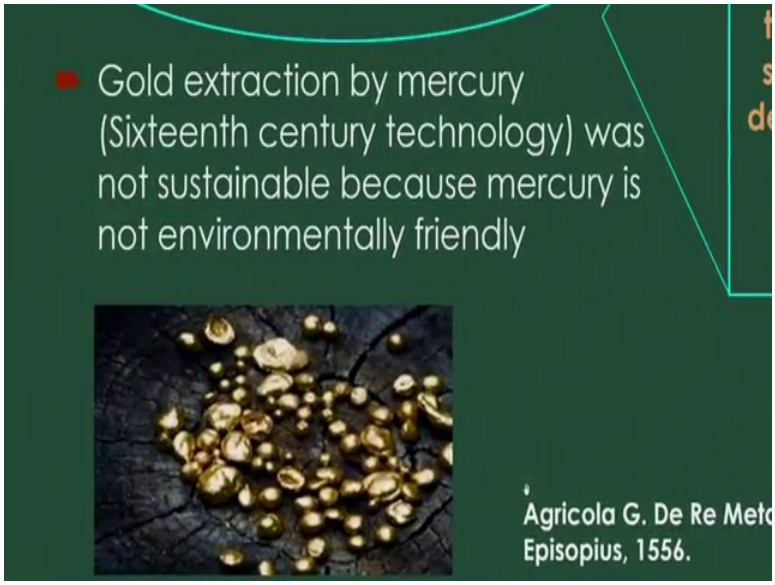

Here it is shown in this picture that how the static mixer that is mechanical prohibitions are produced by which you can produce some, you know that fluid mixing intensified way and this static mixer, how that mixing of these two fluids and getting the reaction there. So, this is the idea that in twentieth century it was actually started that, starting to them, you know that static mixer.

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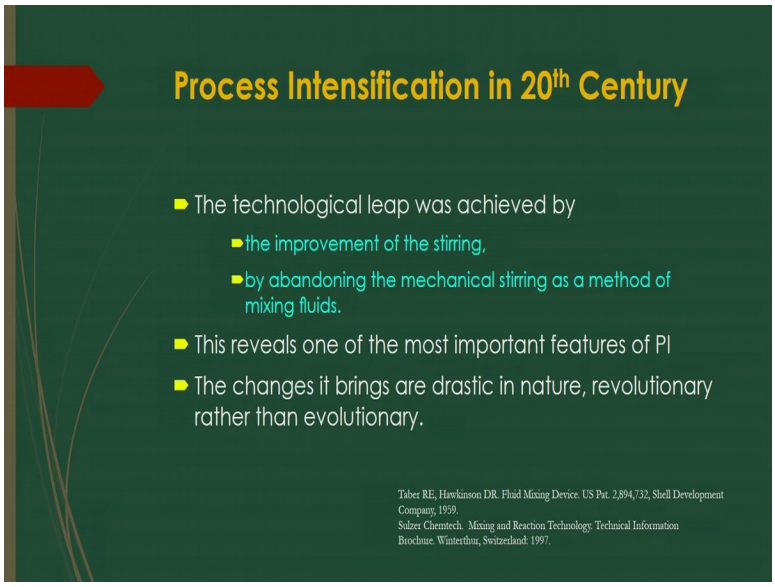

And after that you will see that this all technological leap was achieved by improvement of the stirring and you know that by, you know leaving that mechanical stirring equipment as a method of mixing fluids there. And this reveals one of the most important; you know features of the process intensification and then onwards actually counting. And changes it brings the drastic nature and revolution, revolutionary when you can say that it will be rather than the evolutionary change of that, you know process techniques to get it sustainable way.

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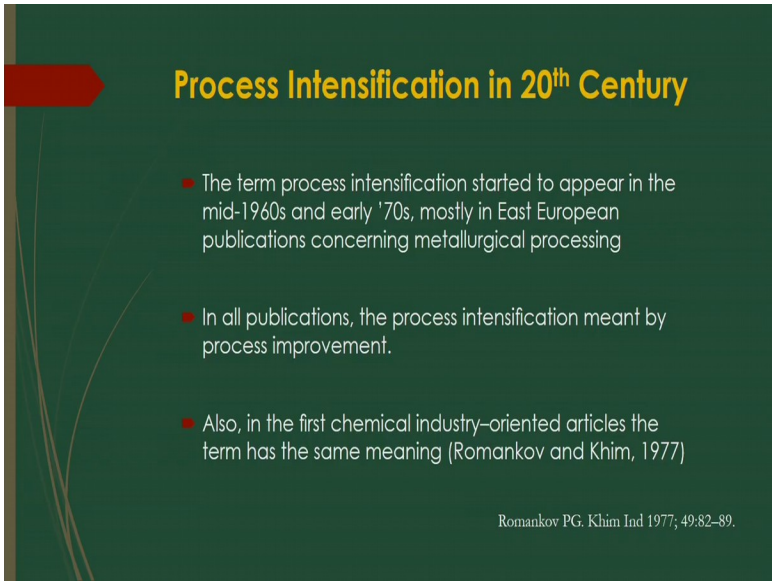

And also, you will see these terms, the process intensification that is started to appear in the mid 1960s and early 70s mostly in East European publications it has been seen and it was

actually, regarding the metallurgical processing what they have published in East European different publication channel they have published. And all their publications it was noted that this process intensification word, they have represented as a process development.

And it was going till, you know that 20th century the first chemical industry-oriented articles also they have used the same word for this process development instead of process intensification. So, it was that period like that, you know process development. But nowadays it is used; it is a simple word that is process intensification. This word is mostly acceptable instead of process improvement process.

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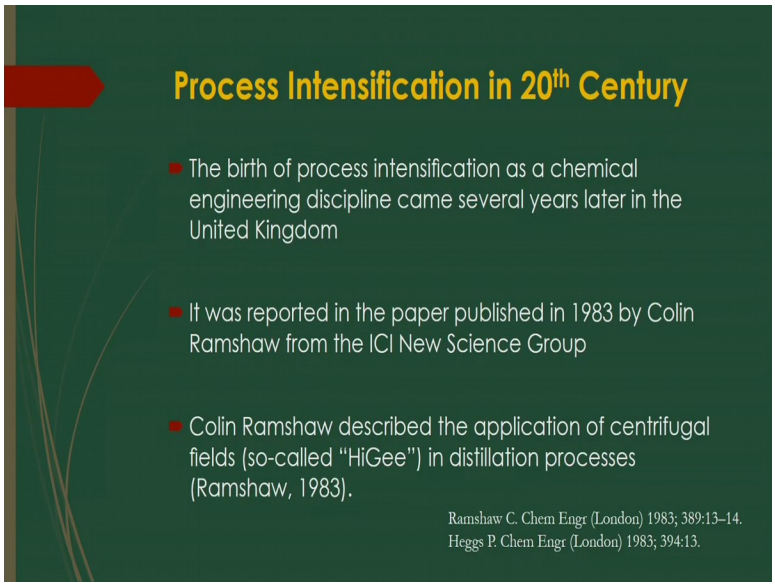

Now we say that what would be that birth of the process intensification as a chemical engineering discipline that actually came several years later in the United Kingdom. So they were the actually king for that process intensification process. Because they have actually reported several research works, that is published in 1983 mainly by Colin Ramshaw from the IC New Science Group. He has published several works regarding this process intensification in chemical engineering process.

And he described the application of, you know that centrifugal force, how it can be used for, you know for distillation process. So that is new, actually idea has come from his publication that conventional distillation process can be intensified by the centrifugal action. Parallelly the adsorption after just treatment of crude, you know that crude oil and then to be adsorbed different contaminants in a, you know certain adsorbent and he has used that you know

centrifugal force how to adsorb those particles there. And those process are actually represented as a HiGee process there from then onward in 1983.

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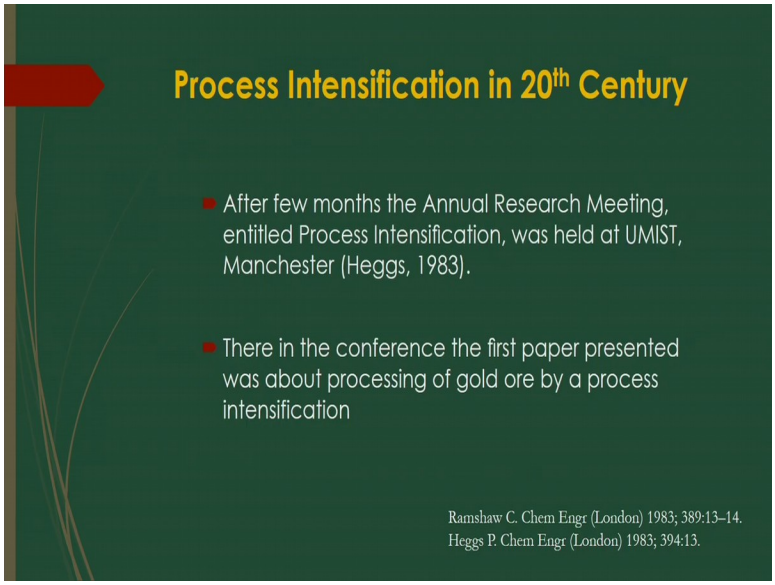

After few months you know that annual research meeting that was regarded as process intensification was held that UMIST that in Manchester that Heggs reported that there in a conference and the first paper that was presented in the conference was about the, you know the processing of gold ore by process intensification. So, from then onward that how this, you know that mercury, use of mercury for the gold extraction is not being used as a process intensification.

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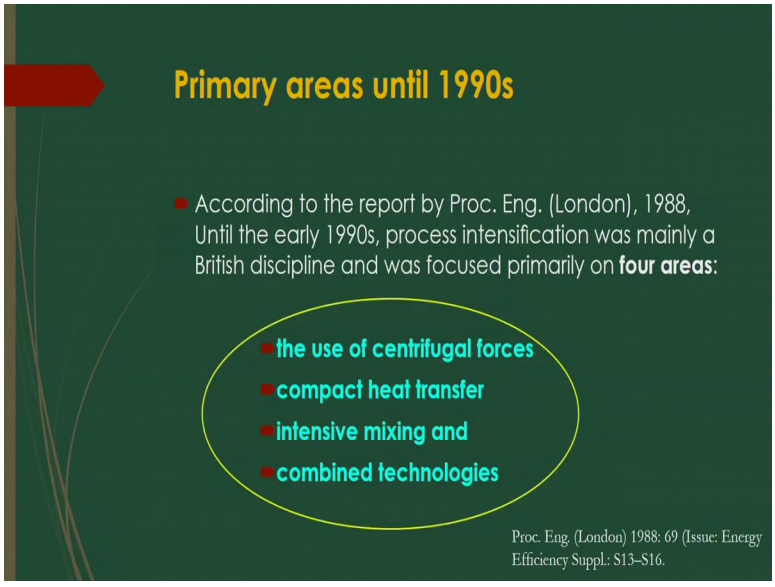

According to the report by that Process Engineering London after that is five years that 1988 you know that early 1990s process intensification was mainly a British discipline that I told that they were king about this and was focused primarily on four areas like use of centrifugal forces, compact heat transfer, even you know that intensive mixing and you know that combined technologies, how actually the process can be done in a combination of the two process in a single unit.

So, combining the technologies when the, you know that making a channel in a compact heat transfer equipment and also the centrifugal force how to use for intensify the process, even the mixing, intensity of the mixing how it can be, you know that improved that has been actually you know reported earlier in 1988 that is report by process engineers in London. So, from then onward the idea is open to all chemical engineering process that how to intensify the process to get the sustainable design for the greener products.

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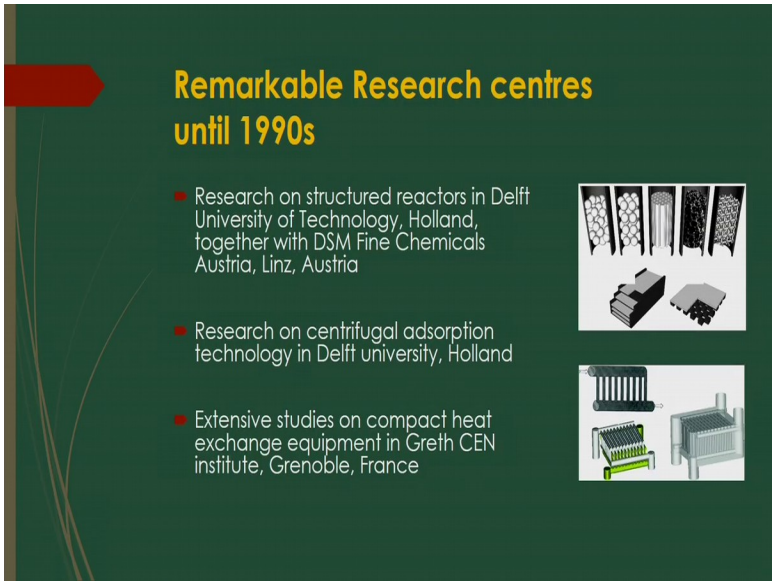

Some remarkable research centers also from then onward it was built in different countries like you know that how to, you know intensify the reactions in a microreactor and in a microstructure reactor to get more contact between the fluids so that the reactions will be fast even when the slow reactions are required you know that retention to be increased there.

So, in that case they have actually modified the reactor different way. They have used different you know structure inside the reactor, sometimes internal, sometimes some packed materials. Even packed materials would be sometimes, you know that structured, made into

structure so that the fluid whenever it would be flowing through that porous structure it will get more contact and more retention time inside the reactor.

So, in that direction research on the structured reactors in Deltt University of Technology Holland they have started and they have actually brought those technology in massive stage and in different industry they have actually used for their technology in commercialized stage.

So, they have, you know that done the research on structured reactors in Deltt University and they have collaborated with the industry like DSM Fine Chemicals and that industry, that is DSM Company they have used those technology to produce fine chemicals based on that microstructure reactor concept.

And Holland also research and development centers they have developed to do the research on centrifugal adsorption process, how to intensify the chemical processes to adsorb the contaminate on the solid particles as an intensified way. So, in Holland also they have started this research from then onward. And extensive studies on concept how to develop the, you know heat transfer phenomena and how to utilize that heat transfer phenomena in a sustainable development for the, you know that heat exchange equipment.

So, they have done, you know several research in the research centers in generally you know that in France they have a lead, actually organization to do these extensive studies on compact heat transfer equipment there in Greth CEN Institute France. So, they have developed that compact heat exchange equipment and it was really a, you know that sustainable development for this heat exchange mechanism.

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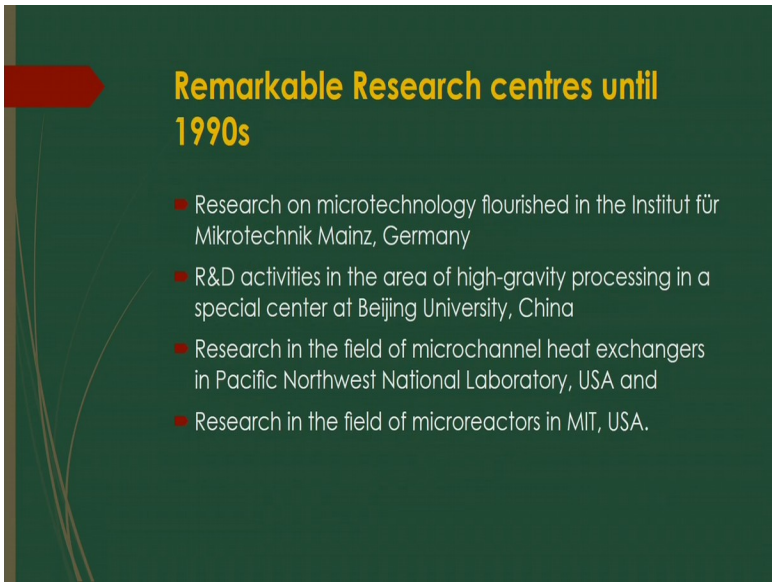

And also research on micro technology that is you know flourished in Institute for Mikrotechnik Mainz in Germany they have done also lot of research on this micro technology which is being used in industry in commercialized state nowadays. And also, several research and development activities in the area of high gravity processing in a special center at Beijing University they have taken initiative for this high gravity processing of this chemical engineering, you know the techniques, that is in China.

And also, micro channel heat exchanger development also, several researches have been done in, you know that Pacific Northwest National Laboratory U S A and also research in the field of microreactors in MIT, USA. They have taken initiative from 1990s onward. Though it has been actually on the research stage before that 1990s but after 1990s they have almost actually came into a, what is that massive stage on this particular process development. And it was commercialized in the market.

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Now commercial scale application in the industry until 1990s what they were in the market that like chemical companies such as the methyl acetate process of Eastman Chemicals, they have, you know that produced this methyl acetate based on this micro technology, based on this process intensification. And also, hydrogen peroxide distillation system also has been developed and it is in the market by, you know that Sulzer

And also, how to produce, you know that hypochlorous acid by process intensification way by sustainable development that has been done by Dow Chemical and they have actually developed those process and now they are using those process there. So, this is the history that you know different process how actually chemical engineering process can be intensified in different way.

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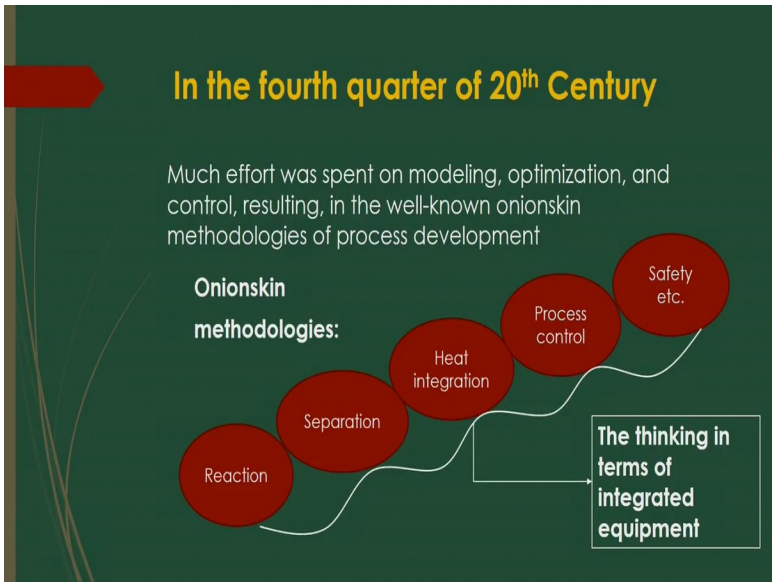

Now you know after 1990s, you know twentieth century what will happen, most of the effort was spent on, you know that modeling, you know, optimization and control. Those results in the well-known onionskin technologies of the process development. Like you know that reaction, how to improve the reaction, separation process, heat integration, process control, safety, etc.

And from then onward you know the thinking in terms of integrated equipment are now coming because you know that if you reduce the number of equipments then your process may be, will be, you know that sustainable way so that you can use less energy and also eco-friendly. Because if you use more number of equipments you need to consume more energy.

Even sometimes the byproducts what will be coming out when also that to run those equipments you know you have to use several other chemicals parallelly in some specific processes. In that case it will not be economic, and it will not be ecofriendly. And that is why the thinking of integrated equipment like in a simple equipment you have to process more than one, you know the techniques and so that you can get the more products for that.

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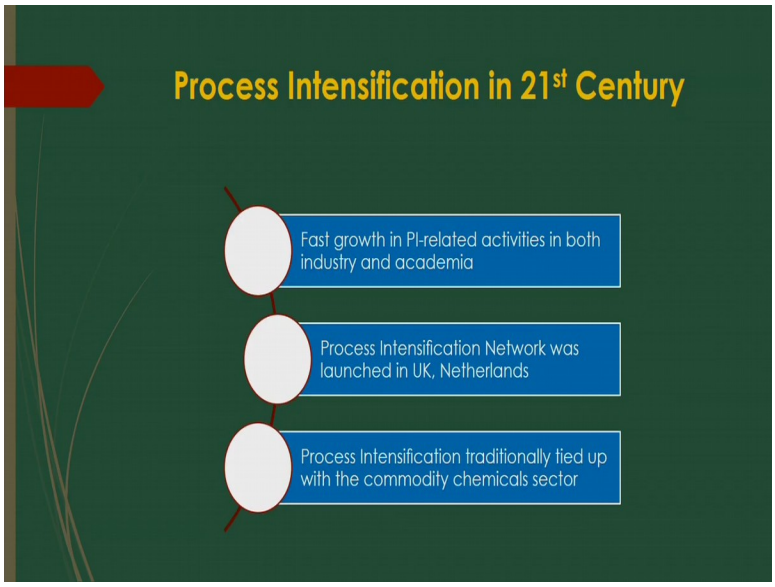

In twenty first century you can say that first growth in process intensification that is related activities in both industry and the academia and process intensification network also was launched in U K, Netherlands there. And process intensification traditionally tied up with the commodity that chemical sector. In that case they have, you know that industry people tried to tie up with the academic people to get this process intensification idea more intensified way, more sustainable way and how to design those process, this 21st century onward that it is, you know that the collaboration started.

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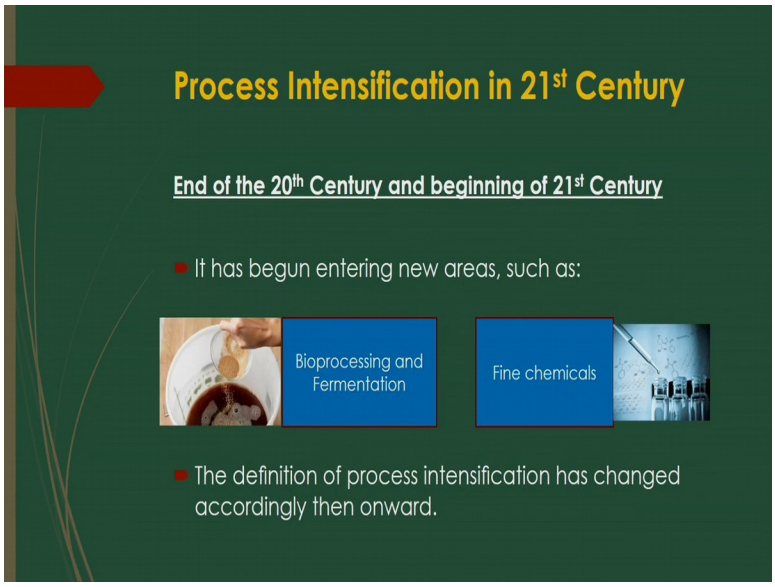

End of the 20th century and the beginning of the 21st century, it is seen that new areas such as you know bioprocessing and fermentation, how to intensify those processes, even how to produce the fine chemicals that is, in Dow chemicals they are producing, even other chemical also, other industry they have started to produce that greener products of that chemicals.

And from then onwards you know that the change of the definition of the process intensification started. So, they have actually released in different way of you know that expressing the process intensification based on that different idea, different you know that what should be the actually goal of that process intensification and how to do that? So, combining all that idea they have just expressing what should be the process intensification actually?

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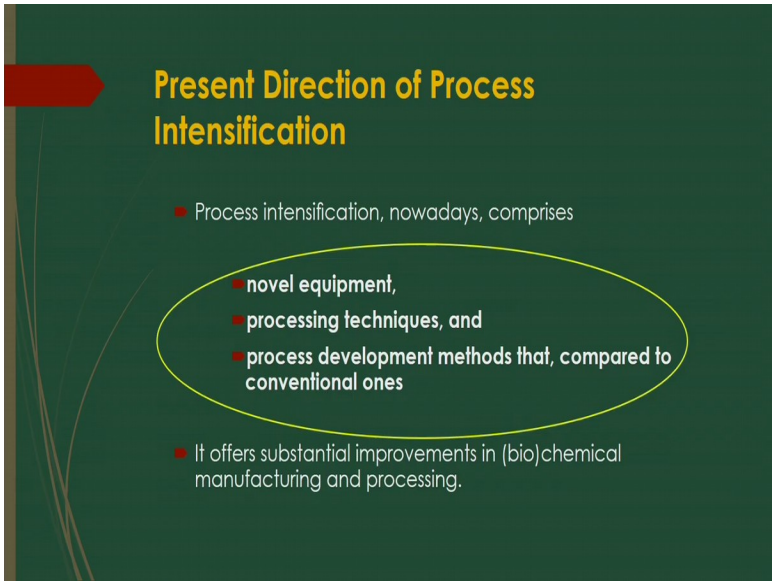

And then onward the direction of the process intensification will come in terms of you know that improvement of the, you know that equipment, just developing a novel equipment, processing techniques to be developed, even process development methods should be improved. Even it will be compared to the conventional one so that how factor of that intensification can be obtained.

And it offered, it should offer the substantial improvements in the manufacturing and the processing. So, from then onwards this, the direction of the process intensification is coming in terms of that equipment, techniques, even methods development, even some other, you know that ecofriendly process.

Even you know that whenever this development will be coming in the market how to intensify the, you know that policy that your products can be, you know sold in the market and it will reach to the consumer in best way so that they can easily purchase those products. And they will be aware of those products, no this is the greenery product, this is the product that is produced by process intensification.

So, based on these, the intensification of the process will be, you know in terms of equipment, in terms of space, in terms of techniques, in terms of methods, in terms of policy, in terms of, you know that idea. So, this several ways you can that intensify the process. That definition will then come in that direction.

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Now what will be the status then, today's status of that process intensification? Now this process intensification has or will have a major role to play in the future of chemical engineering that we can say. Because that 1556 onward that idea has come to have intensify the anyway, process. No way that you should use that old process for producing the products, because those are not economic and those are not ecofriendly because environmental impact is main concern nowadays so that you have to produce the product in such a way that there should not be any bad impact on the environment.

So as for statement of Charpentier, 2007, he told that, the process intensification should be from the molecules to the money. And it should be in terms of processing and the processing should be proposed in such a way that chemical engineering mostly you know that main products, most of the products that is coming based on this chemical engineering process. So,

the chemical engineers should take a role in that concern of these molecules into money in such a way that they should drive today's economic development and wealth creation based on this, you know that intensification process.

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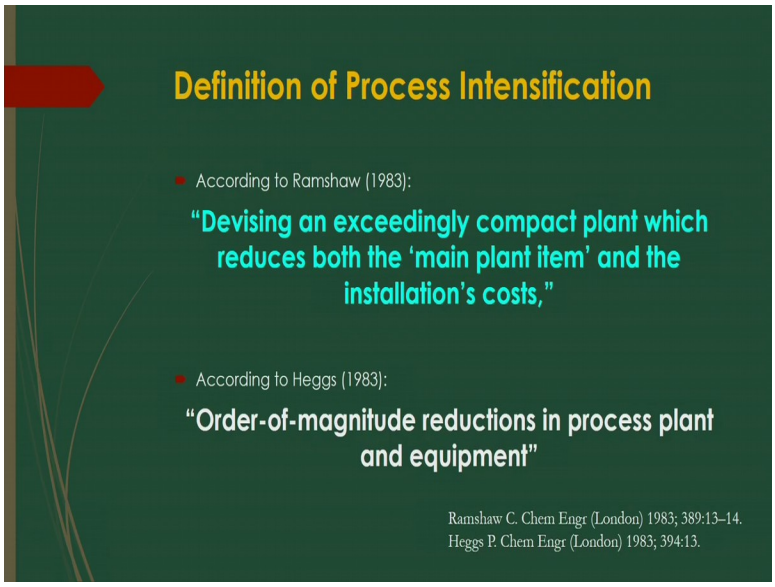

Now what should be that, the definition of that process intensification? In 1983 Ramshaw, he has given one statement for this definition of this process intensification. According to his, that, he told that the devising an exceedingly compact plant which reduces both the main plant item and the installation costs will be the process intensification theory. Means here you have to device the equipment in such a way that it should be very compact.

It should be, you know that in such a way installed that your space should be less, and also their number of equipment should be reduced in the main plant and also there should be less installation cost. So, this is the main, actually concept that is given by, that is Ramshaw as his definition. After that 1983, Heggs also he has given some statement regarding this process intensification. It is the order of magnitude, reduction in process plant and equipment.

So, this process intensification is the order of magnitude, reduction in process plant and equipment. That means here you will see that means the same statement almost same; that he told that the process plant should be less spacious and also you know that number of equipment should be less. So as per that definition this process intensification like this.

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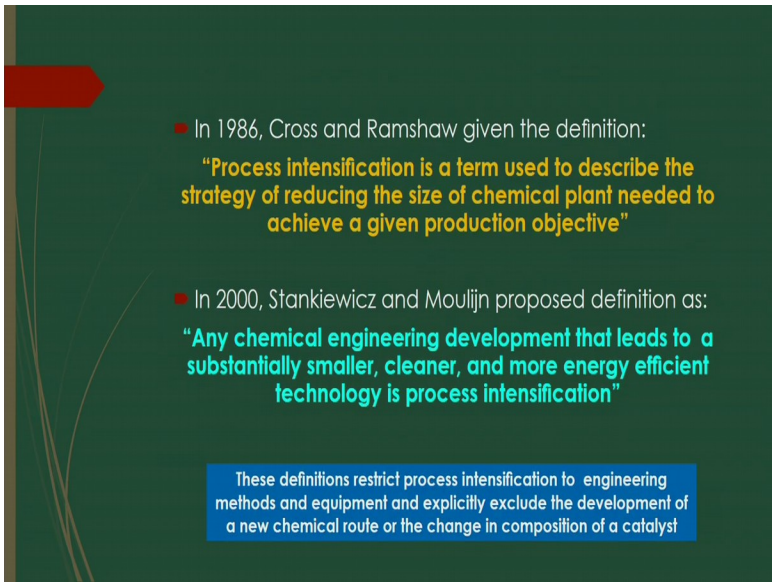

In 1886, later on after again 3 years you will see that Cross and Ramshaw again given the definition of process intensification as they told that this process intensification is a term that will be used to describe the strategy of reducing the size of the chemical plant needed to achieve a given production objective. To give the process plant in such way that it will occupy the less space and give more production.

In 2000s, Stankiewicz and Moulijn proposed definition as any chemical engineering development that leads to a substantially smaller, cleaner and more energy efficient technology that should be process intensification. So as per his definition also it is very clear that the process intensification should be in such a way that it should be the, that means the process should be substantially smaller, cleaner and more energy-efficient based technology.

And these definitions of course restrict the process intensification to engineering methods and equipment and explicitly exclude the development of a new chemical route or the change in the composition of the catalyst. That means here these definitions does not seem to give the method developments. And you know that new chemical route; it does not say that what should be the new chemical route, new chemical methodology and how to change the composition of the catalysts which are being used for reactions, so these definitions. So later on, also those things to be actually considered as a process intensification.

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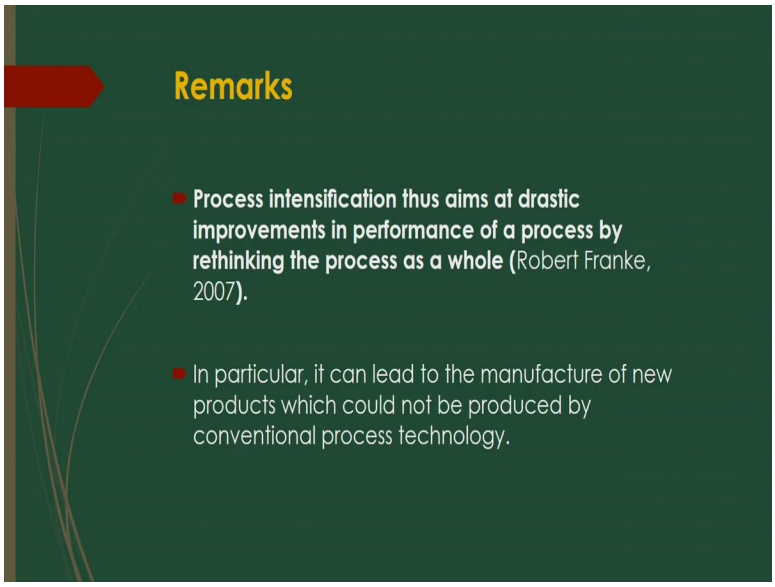

Now, in this case what remarks we can made that the process intensification thus aims to drastic equipments, improvements in performance of a process by rethinking the process as a whole. So, this is given by Robert Franke in 2007. He told that the process intensification should be aimed as improvements in performance of a process by rethinking the process as a whole. In particular it can lead to the manufacture of new products which could not be produced by conventional process technology.

So, in this case he told that if you are going to produce the new products, Ok so you cannot get that sustainable process development to produce these products by the conventional technology. So, you have to change that, you know conventional process technology, get its process intensification and get its the final products, ok the new products based on this process intensification.

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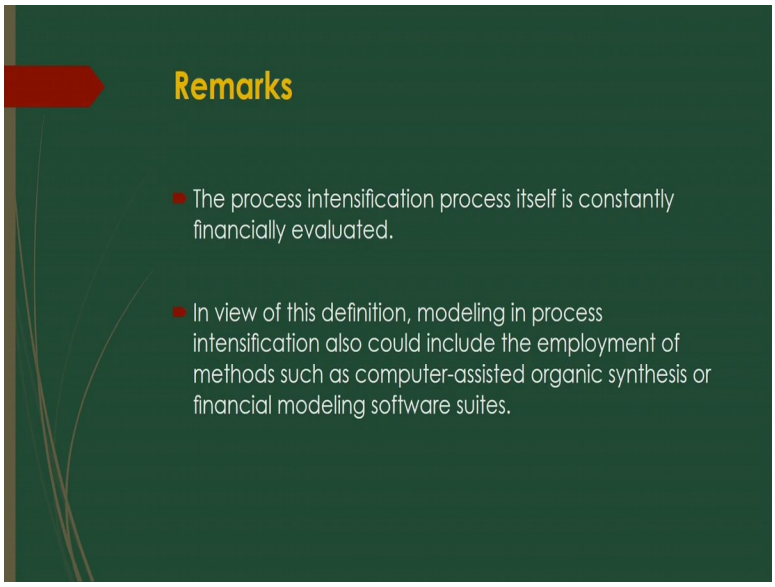

And then in view of this definition, modeling in process intensification also could include the employment of methods such as computer assisted organic synthesis or financial modeling software suites. Sometimes you will see in chemical engineering process, to analyze the process, how economic this process and also how optimized way this process can be developed, designed, that is required. So, in that way to intensify the process one should also include for this process intensification concept for the optimization process. And also, computer-based design of chemical engineering process, what is coming based on the process intensification way.

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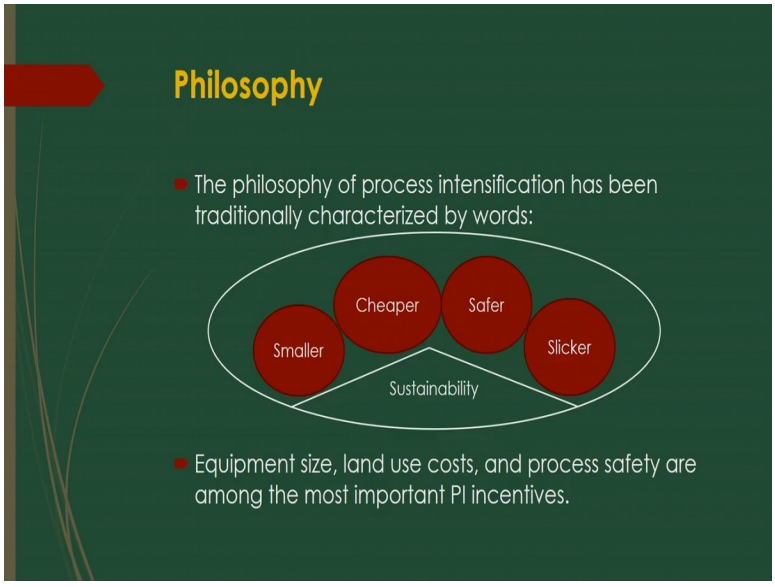

Now, what is the philosophy of that, then process intensification? The philosophy of the process intensification has been traditionally characterized by these few words like smaller, cheaper, safer, sleeker and sustainability. These five words should very important for this process intensification. Smaller means you have to, you know that procure some equipments very smaller. Nowadays that is why, like it is coming macro to micro then nano.

Cheaper, of course, it would be cheaper because it should be more economic. It should not be consumed more energy for that so that the product should not be very, you know that precious. So, in that case you have to produce the product in such a way that your product should be cheaper. Safer also, whatever products you will be producing by this process intensification that should be safer. That does not mean that whatever products is coming that should be, you know that hazardous. It will impact on your, you know social health concern. So, it should be safer.

And also, sleeker. Sometimes you will see that, you know that sometimes you know distillation column, you will see that big, big distillation column, you have to reduce that size of the distillation column to produce that or refine the oil. And also, sustainability. You have to design that process in such a way that it will last for long time. Not like that, Ok only for two years, three years it will last and later on you will say that this process is not actually working in better way so it should be, you know avoided.

Not like that, you have to produce that process in such a way or design a process in such a way that should be long-lasting Even it will be ecofriendly and economic. Equipment size, land use cost and process safety are among the most important process intensification incentives. So, you have to keep in mind that you have to intensify the equipment, you to intensify the cost, you have to intensify the safety and also other process techniques.

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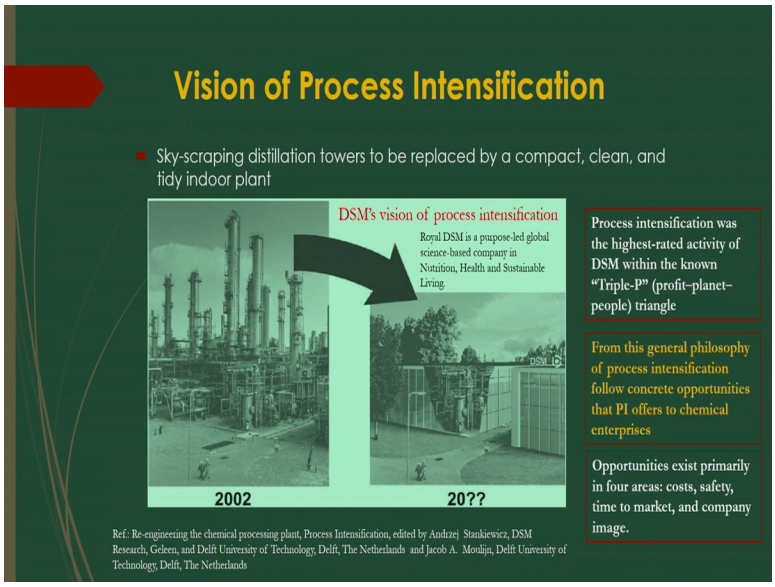

Vision of the process intensification, like here, like sky scraping distillation towers, that towers you know that... I told that the distillation tower, big, big distillation tower, long distillation tower should be, you know that replaced by a compact, clean and tidy, you know indoor plant like this here.

So, this 2002 onwards this, you know that distillation processes are being intensified. Now how this process or how this plant to be intensified in a compact, clean and tidy plant, that is the main goal in the process intensification field. So, process intensification was the highest-rated activity of the DSM company there.

So according to this DSM they have their vision like this. From 2002 to 2000 you know that there is no end when it will be coming in. So, they are trying to, you know that intensify the process to, you know that sky scraping distillation towers to be replaced by the compact, clean and indoor plant. So, in that case they are trying and they are actually, you know they are following some, you know handy rule like this triple P Rule like profit, planet, people triangle this map road for their vision.

And from this general vision or philosophy you can say of the process intensification, follow the concrete opportunities that process intensification offers to chemical entrepreneurs. And also, you will see that opportunities that exist primarily in four areas like cost, safety, time to market, even the company image. So, these are the main, you know vision of this processes that is given by this DSM company.

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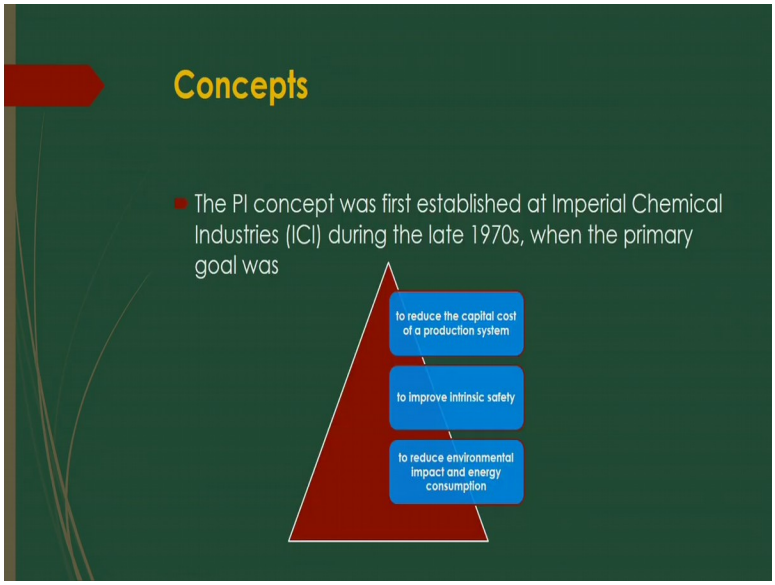

And also based on their vision, some concepts they have developed, that the P I concept first established at, you know Imperial Chemical Industries during the late 1970s that when the primary goal was there to reduce the capital cost of a production system, to improve the intrinsic safety, even to reduce the environmental impact and energy consumption there.

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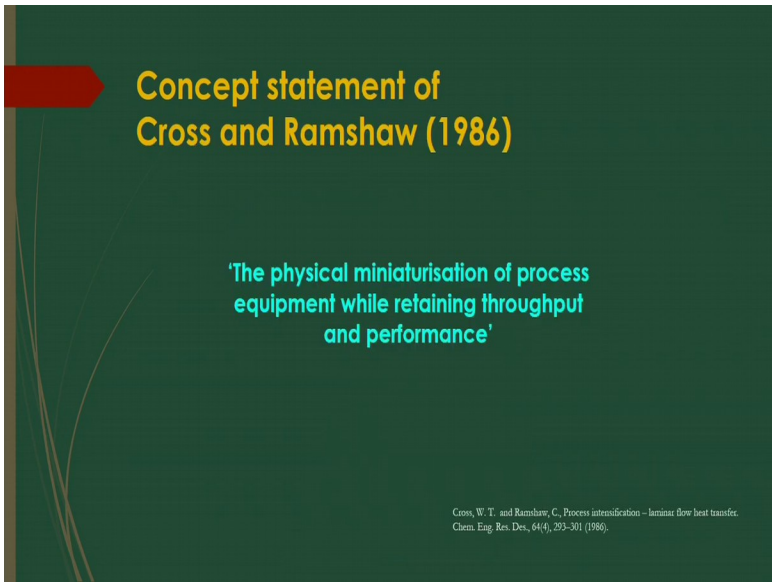

Now concept statement of Cross and Ramshaw, 1986, they have given this concept that physical miniaturization of the process equipment while the retaining throughput and the performance. So, this is the concept of statement of the process intensification that is given by Cross and Ramshaw.

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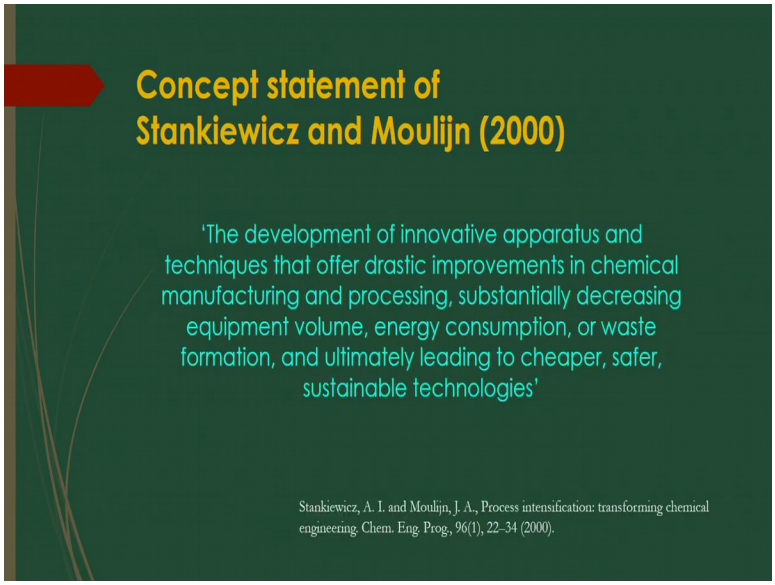

Again, the Stankiewicz and Moulijn, 2000's they have given this statement for this concept of process intensification as they told that the development of innovative apparatus and techniques that offer drastic improvements in chemical manufacturing and processing, substantially decreasing the equipment volume, energy consumption or waste formation and ultimately leading to a cheaper, safer and sustainable technologies. So, these are the concept they have given in their publication that what should be the actually concept of process intensification.

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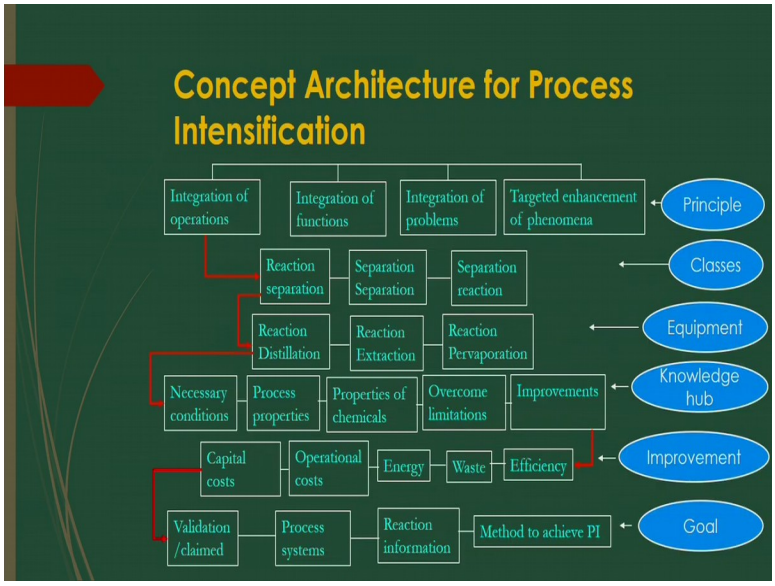

And some architecture they have given for this process intensification like they have divided that process intensification area into first four parts like integration of the operations, integration of the functions, integration of problems, even targeted enhancement of the phenomena as per their principles. What should be the principle of that process intensification?

And then based on these principles, one of the principles like integration of the operations, the main heart of this chemical engineering process, process intensification and they have classified these process intensifications of this integration operation into a reaction separation, separation and also separation reaction in different way.

They have actually classified this integration like this, reaction and separation should be at a time, separation both should be in a compact way, separation and reaction should be both simultaneously be working. And also, you know that reaction separation may be, you know that reaction distillation, may be reaction extraction, may be reaction pervaporation like this.

Even reaction distillation will be like this, necessary condition should be, you know that compiled. Even process properties to be known, even properties of the chemicals, even how to work on the limitations of that process and how to improve that way. So, for that, knowledge hub is required for this. And also, for the, you know that reaction separation processes, there, you know that intensified equipment should be required.

And also you know that for improvements of those, you know necessary conditions, process properties, properties of the chemicals and to work on the limitations you need to have certain, you know parameters like capital cost, how to again then, you have to use the less energy, operational cost you have to use less, you know that, that is economic way you have to develop those process, even energy consumption should be low, waste, waste should be in such a way that should not be, you know the hamper the environment.

Even efficiency, you have to produce those products efficiently so that it would be ecofriendly and also not injurious to the health. And you know that, after that what you have to do that analysis of this improvement you have to go to the goal based on the validation process system, even reaction formation, even you know that other parameters. You have to consider to go to that final stage of this process intensification method.

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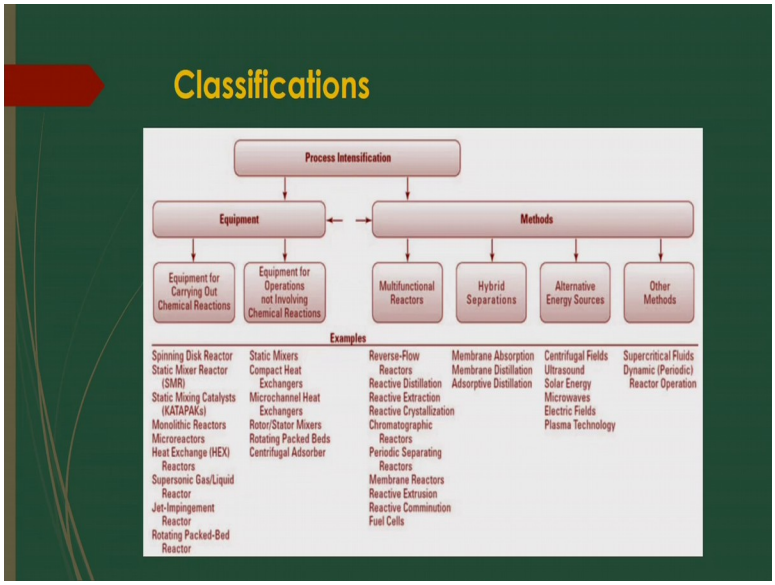

Some classifications of this process intensification methods are given here. Like you know that equipment, methods, if I classify this way, if we classify the equipment as equipment for carrying out chemical reactions, equipments for operations not involving chemical reactions. Even some methods should be developed in such way that multifunctional reactors should be there, hybrid separations can be developed. Even alternative energy sources, even you know that other methods to be developed based on this process intensification.

Now, some improved or some, you know that for process intensification, some equipments are developed like this spinning disk reactor, static mixer reactor, static mixing catalyst even monolithic reactors, micro reactors, heat exchange even supersonic gas liquid reactor, jet impinging reactor, even rotating packed-bed reactor, some static mixer for improving the mixing process, compact heat exchanger, micro channel heat exchanger for increasing the heat transfer

Ever rotor stator mixers also, rotating packed-bed to get the, you know that more interfacial area and more contact, even centrifugal adsorber to intensify the separation process, even sometimes you know some other processes like this reverse flow reactors, reactive distillation, reactive extraction, that means conjugation of the reaction as well as crystallization, you know that chromatographic reactors, periodic separating, reactors, membrane reactors even to separate that fine particles by this membrane reactors, reactive extrusion to produce that polythene,

Even reactive, you know that comminution, you know sometimes you know that to reduce the size of the particles you have to use this comminution process, so for that sometimes,

reactive comminution also nowadays very interesting and it gives the process intensification. And fuel cells also important, membrane absorption, membrane distillation, adsorptive distillation those are under process intensification. Those process are coming based on that intensification of the process.

Like centrifugal fields, even ultrasound, nowadays huge application of this ultrasound, solar energy, how to utilize that natural source of energy from the solar, that how to use those process, even microwaves, electric fields, phase technology, plasma technology, supercritical fluids even dynamic reactor operation, how to all those things so all are coming in the process intensification. So, all those processes developed based on this certain, you know that process design and these are of course developed for the intensification of the process.

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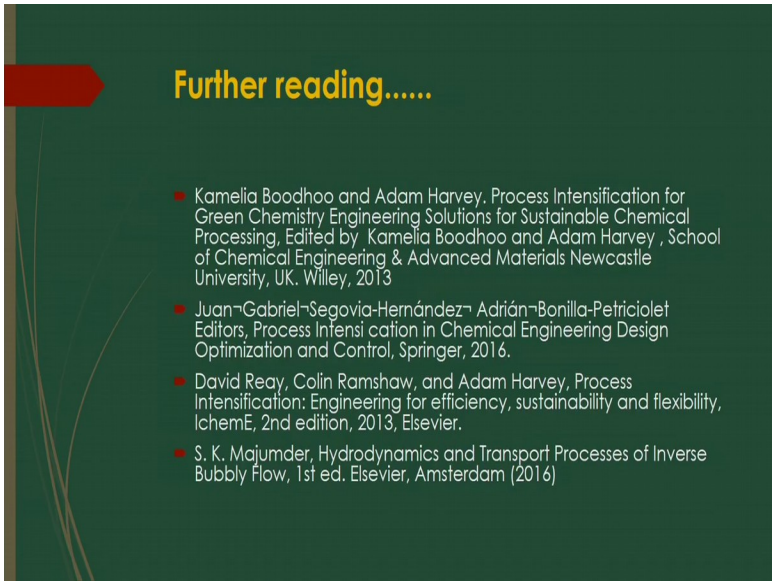

And I would suggest you read further regarding this introduction of this process intensification, even more details also you can get more information, I would suggest you read those here given this textbook for the process intensification. You can follow my book also here S. K. Majumder, Hydrodynamics and Transfer Process of Inverse Bubbly Flow. This is one of the important ways to produce the process of chemical engineering for gas liquid process, to get more retention time for the chemical reaction as well as physical operations.

So, in this lecture we have gone through some, you know that brief history of the process intensification, what should be the classification, and what are the concept and definition of the process intensification. So, it would be helpful for you. Next class onward, next lecture

onward we will describe or discuss something more about that process intensification as per course content. Thank you!