Chemical Process Intensification
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Lecture 12.1 (lec33)
Introduction to Microprocessor Technology

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Welcome to massive open online course on Chemical Process Intensification. So we have discussed a lot of information about the chemical process intensification up to module 11. Now In this module, module number 12 we will discuss something more about of process intensification. And in this module it will be regarding Micro process Technology for process intensification.

And in this lecture under this module we will try to discuss something about what is that micro process Technology? And also how that microprocessor technology will be that considered for process intensification, what is the direction of that process intensification of this micro process Technology?

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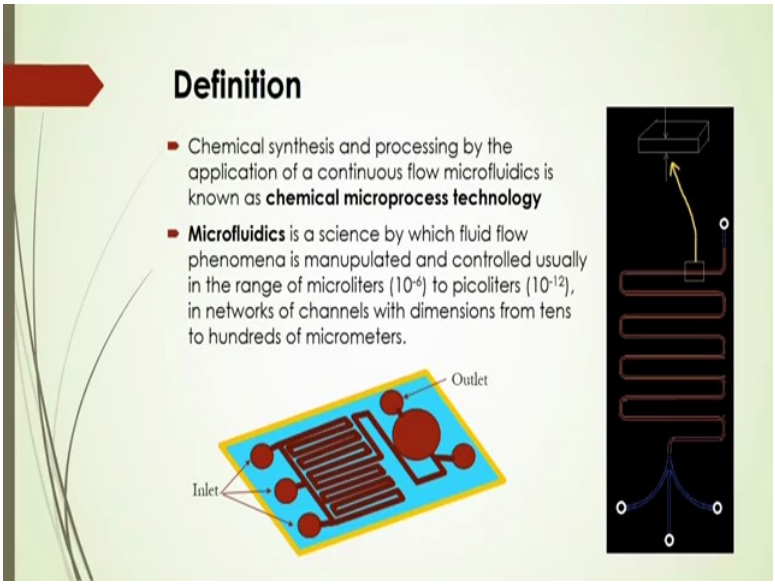

Now before going to that we have to know the terminology for this micro process technology and what is the definition of those terminologies which have been used for that micro process technology for the process intensification? Now if we talk about that micro process technology we will see that there will be a certain process in chemical engineering where you will see that the process of different chemical engineering like absorption, even reaction system that is done in a continuous flow system. And where that the flow system will be control in such a way that it will be flowing through the micro size continued where getting some special advantages whenever that flow will be flowing through that micro size conduit.

Now if you consider that supposed chemical synthesis and also some other processing by that application of continuous flow systems, it is sometimes called microfluidics and which will be actually regarded as chemical micro process technology. And this microfluidic is actually a science by which that fluid flow phenomena will be manipulated and controlled usually in the range of microliters like 10 to the power minus 6 to picolitres of volume in networks of channels with the dimensional from tens to hundreds of micrometers.

Here in this slide we are showing one microfluidic system where you will see that some fluid will be entering to that inlet and it will be will be passing through some micron size channels and it will be coming out and during that flow there will be a certain advantages of that fluidic flow through this dimensions of this micrometers. And that will be discussed that is successively there in the lecture.

Now this is the things that through that volume of that very small amount like microliters that will be actually considered whenever any chemical synthesis process to be done in that

micron-sized channel. And based on that micron-sized channel when a reactor is being procured it will be called as micro reactor. Now there will be certain specific application of those microfluidic systems even micro reactor systems based on this micro channel based micro reactor.

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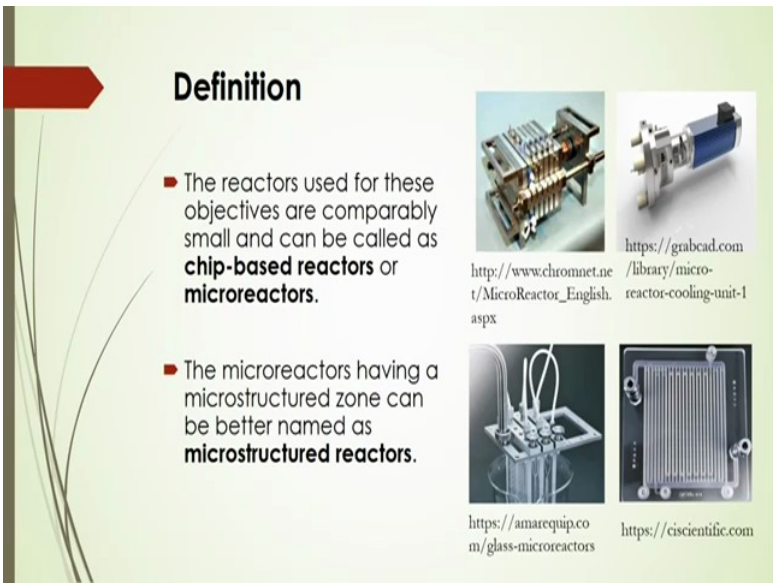

And the reactors that is being used for these objectives are comparatively very small and also it can be called as chip-based reactors or it is sometimes called Micro reactors. And if the micro reactors having a micro-structured zone, there may be multiple number of micro channels will be arranged in an array or some other provisions that mechanical provision or some other that way for arrangement of that micron size conduit or micron-sized devices in a particular zone then it can be it can be regarded as better named as micro-structured reactors.

Here see there are several different types of micro reactors as shown in the slides. That is taken from that website it is given here. So this is one of that micro reactor that is glass micro reactor this is channel based micro reactor where micron sized channel are actually procure in a glass system. So that whenever flow of particular process system will be coming into the reactor and it will be coming out during that flow to the channels there will be gaining some process intensification.

So micro channel based process intensification will be here in the Reactor where this procured based on that micro channel. Here some other synthesis of the chemicals through this Micro reactors like this type of where the channels will be micron size and it will be design in such a way that there will be Micro mixing inside that channel. Just making and even grouping and some other fashions of micro channels to get that intensification of the mixing and also intensification of the yields of reactions that is being done for the Chemical synthesis.

And here also there is another micro reactor system where you can say that there are array of micro channels are placed in such a way that systems are being actually scaling from one channel to the hundreds of channels there even than more than that. And it will be procured in such a way that Successively or consequently you can say or parallelly more than number of reactors micro channel based reactors will be procured, so that you can get that more yields and also that more efficiency for that Chemical synthesis. That may be in terms of residence time of the reactor even less amount of solvent using even some other process intensification aspects that will be applied for that micro reactor system.

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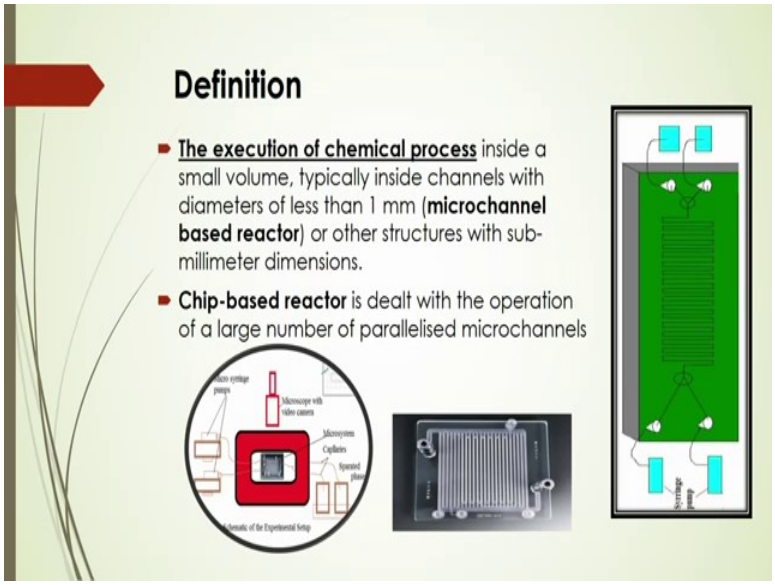

And also the execution of this chemical process through this Micro reactor or micro channel based reactor is very important in that. Because the volume is very small that execution of that chemical process inside that small volume typically inside that channels with the diameter that is less than 1 millimeter or other microstructure with sub millimeter dimensions here is very complex. And you have to precisely device that micro reactor just by considering that micro channel array having that micro mixing and even other mechanism, so that that there will be intensification of the process there.

Now chip based reactor is also one important aspect of that basically the same name that micro reactor. In this case that to be dealt with the operation of large number of parallelized micro channels there. So it is called chip based that is CR. This is one chip where that micro channel will be arrayed in such a way that there through that channel a liquid will be flowing. And there will be application of this type of liquid flow through that micro channel maybe for

Chemical synthesis even absorption and adsorption systems there for getting that more interfacial area as well as some other advantages that will be discussed.

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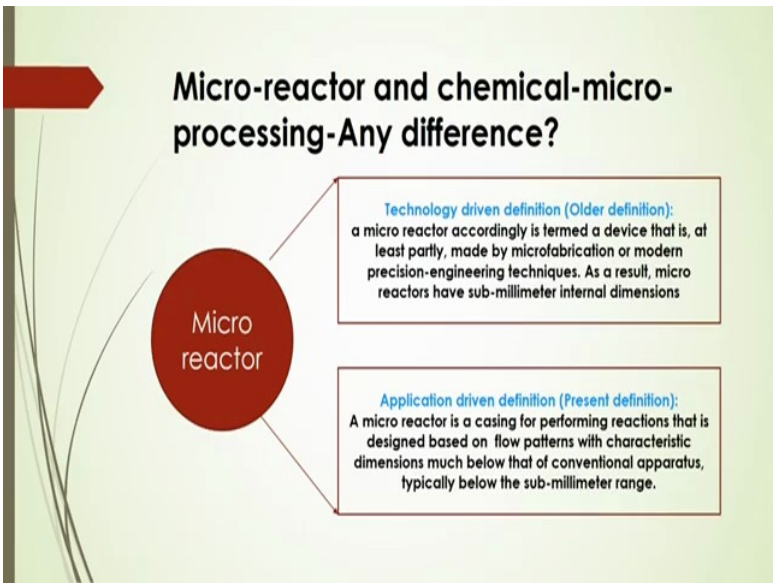

Now question is that is there any difference of micro reactor and the chemical micro processing or not? In earlier stage there is that, as per earlier definition that micro processing actually it is regarded as Technology driven definition of micro reactor. In that case micro reactor accordingly is termed a device that is at least partly made by micro fabrication or you can say that modern Precision engineering techniques. As a result that micro reactors have some millimeter internal dimensions.

Now present definition will be something different from that as per that present definition what is that, it is considered that this micro reactor will be a casing for performing reactions that is design based on the flow patterns with characteristic dimensions that will much below that of conventional apparatus, typically below the sub millimeter range.

So there are two types of definition one is technology driven definition and other is application driven definition. Earlier is that the definition of the micro reactor is basically based on technology driven definition, whereas nowadays this micro reactor is defined based on the application driven definition there.

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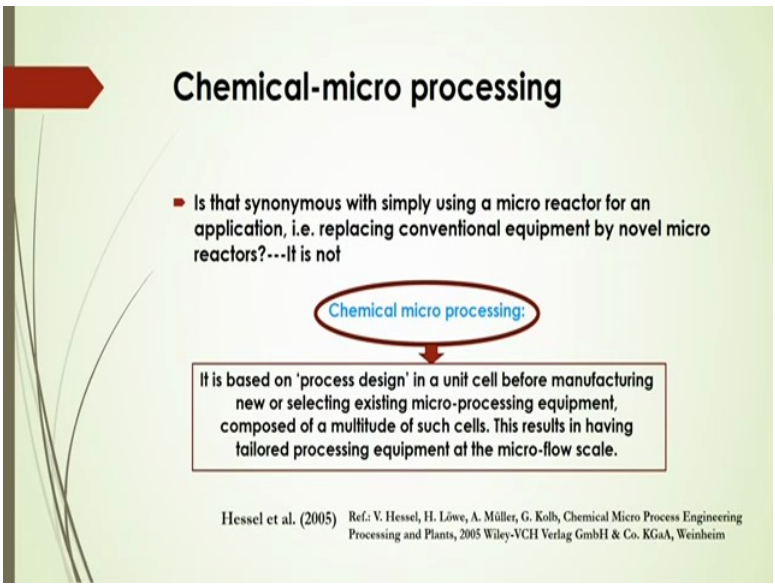

And is that synonymous with simply using a micro reactor for an application or some other terms will be used for that. If you that is replacing conventional equipment by the novel micro reactors then what will happen? Whether it should be suitable or not. No it is not there because that chemical micro processing it is generally based on that process design in a unit cell before manufacturing new selecting existing micro processing equipment that is composed of a magnitude of such cells. This results in having tailored processing equipment at the micro flow scale.

So this definition actually given by Hessel et al. 2005 in their books they have actually stated that no, there should not be that synonymous of the simply using micro reactor for an application that is replacing that conventional equipment by novel micro reactors. So this chemical micro processing actually should be based on that process design in a particular unit cell before actually manufacturing new or selecting existing micro processing equipment there.

So in that direction that you have to define that how chemical micro processing will be there. So these things very important that you have to remember how that chemical micro processing is actually different from that micro reactor system.

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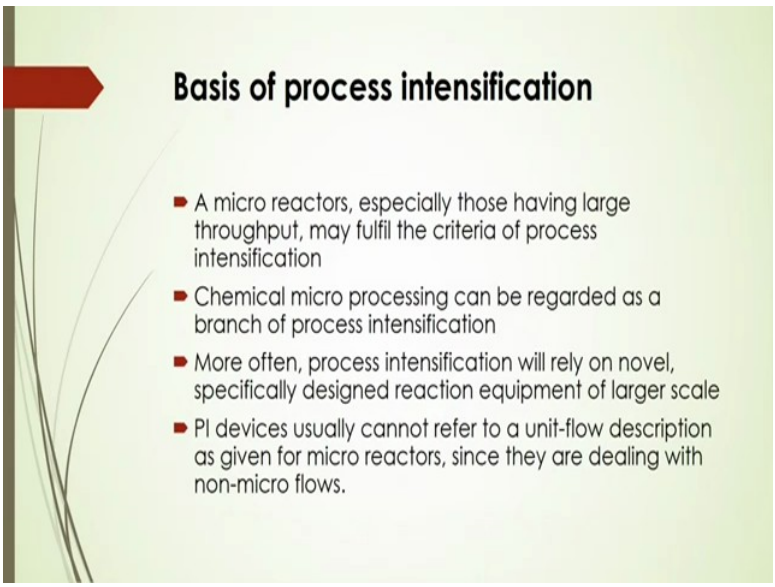

Now basis of process intensification very important that, that you are going to use microprocessor technology for that chemical process intensification or other things, so in that case what should be the basis of that process intensification? Now a Micro reactor especially those having large throughput may fulfill the criteria of process intensification. And in that case that process intensification devices can be regarded as a branch of process intensification based on the chemical micro processing.

And in that case that process intensified devices usually cannot be referred to a unit flow description as given for micro reactor. Since they are dealing with non-micro flows. Also you can say that process intensification will rely on novel, specially designed reaction equipment of the larger scale. So that is why this should be the basis for that micro reactor especially those having large throughput may fulfill the criteria of process intensification.

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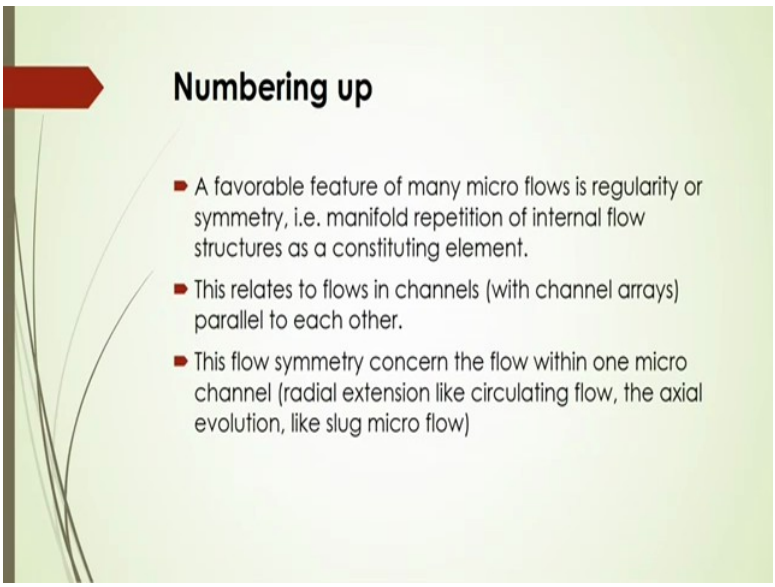

Now in this regard it is very important whenever you are going to apply this micro process technology just by developing that process intensified device. Then you have to think about that not only just using the single channel. It will not be actually economic or you can say that it will not be that large scale application, so in that case you have to think about that numbering of that channels. So instead of one channels may be more than hundred 1000 channels will be there even more also based on that process intensification specific application also.

Now a favorable feature of many micro flows is regularly or symmetry. In that case the modified that micro reactor based on that just having more than one channels will be there so in that aspect if you are considering that micro flows to be in regular fashion or a symmetry. So in that case that manifold repetition of that internal flows struck to be considered and that should be considered as a constituting element there.

So this relates to the flows in channels with Channels array parallel to each other. So this flow symmetry that will be concern the flow within one micro channel that may be scaling or numbering of two way several numbers to get that same impressions of that symmetry of the Flow. And whenever you are numbering of that Channel, you will see that just considering the same Symmetry you can get parallel Symmetry of that flow.

And there may be you can increase that residence time even also for that yield of the process will be increased for that and also successively you will see that there will be a flow pattern

changing from that particular single phase to slug flow and then there will be intermittent and then slug and then churn there will be there and also in that case if you are using more than one channel that this also can be procured if you array that channels successive one by one and parallel in parallel way.

But this is the advantage that you may not get that radial extension of the flow when you are using that micro channel. But in case of conventional channel that is more than 1 millimeter there may be internal circulation of the flow, there may be axial evolution but whenever you are getting the slug flow surrounding the struck with some other circulation even some drop information.

Even there will be some, it is called stagnation zone at that end of the slug flow and at the end of the slug there in the channel. So the flow symmetry to get it through the channel you have to consider not only that single channel of micron size diameter, it may be parallel even with more than one channel there. And also micro flow processing the repetition of that unit cell, here is one channel to that 10 channels typically.

Not only whole set the laboratory scale that maybe you know apply to the smaller to larger even production as well. So this is as if by just numbering of the elements that is by multiple repetitions of the small precisely structured reasons there. So that is call that Numbering up that is from one channel to the up to you now desired number of channels that as per process application.

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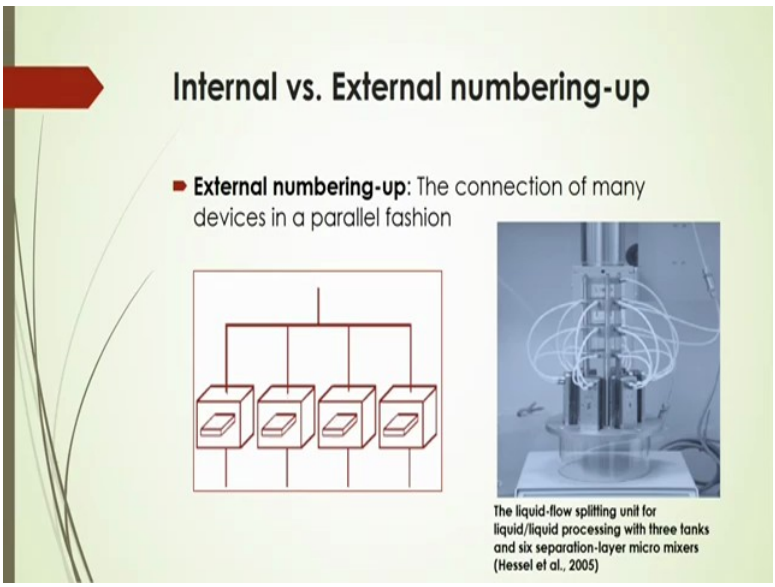

Now there may be two types of numbering up, one may be that internal another maybe external numbering up. In case of external numbering up the correcting of many devices in a parallel fashion that will give you external numbering up but in a single reactor there may be more than one channels will be arrayed but this external means there are connections of many devices here they are in a parallel fashion.

It is shown in this figure as that here one device, another device, another device, so more than one devices here, typically four devices are arrayed, connected in a parallel fashion. So this is called external numbering up.

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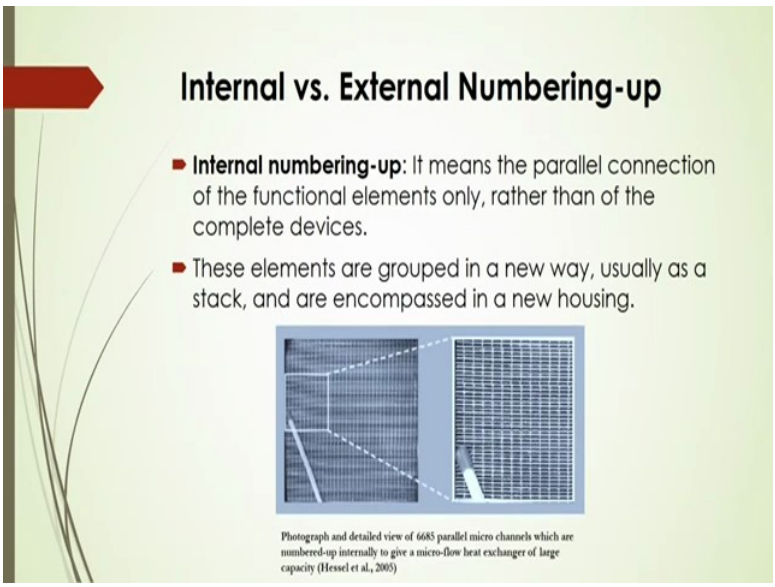

Whereas internal numbering up it will give you functional elements only rather than of the complete devices that will be connected parallel. In this case the functional elements are grouped in a new way, usually as a stack encompassed in a new housing there. So here you see, as shown figure in the slide that is there that how you will see the internal numbering up is there.

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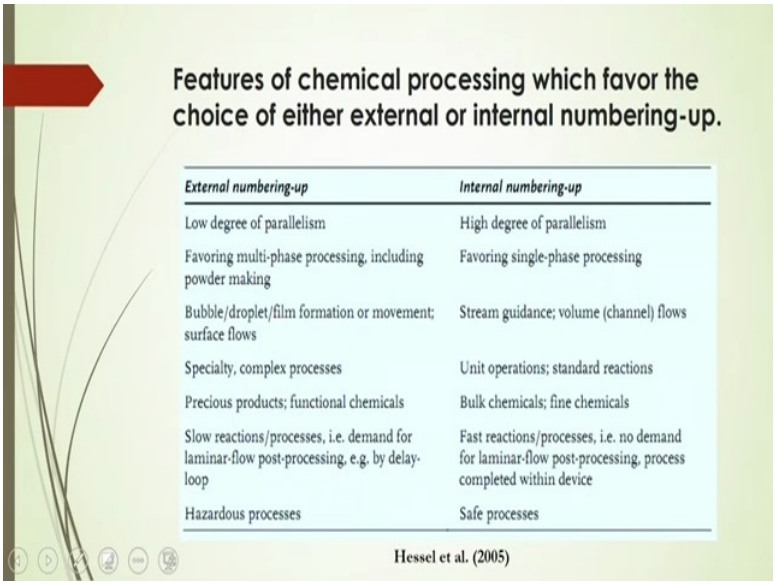

And some features of that chemical processing which favors the choices of either external or internal numbering up. Now maybe you will see that if you are using that external numbering system of that micro devices, so in that case you may have that low degree of parallelism,

favoring multiphase processing including power making. In that case bubble, droplet, film formation or movements surface flows, these are some features.

Specialty, complex processes will be there and also sometimes that products will be very precious and also there may be functional chemicals that you can use for synthesis. And in this case you will see some slow reactions are process will be there and also there are several demands for that lamina flow, post processing just by delaying loop in this particular external numbering up. Whereas you can handle hazardous processes also by this external numbering up system.

Whereas in case of internal numbering system, high degree of parallelism you can get compare to their external numbering up. Also internal numbering up it has advantages over that external numbering up because you are favoring single phase processing there. Whereas it may give that unit operations of standard reactions and also it may be faster reactions that may be processes, no demand for lamina flow post processing process even completed within devices you can say and also safe processes since you are using one single devices conjugated with several number of parallel channels configuration.

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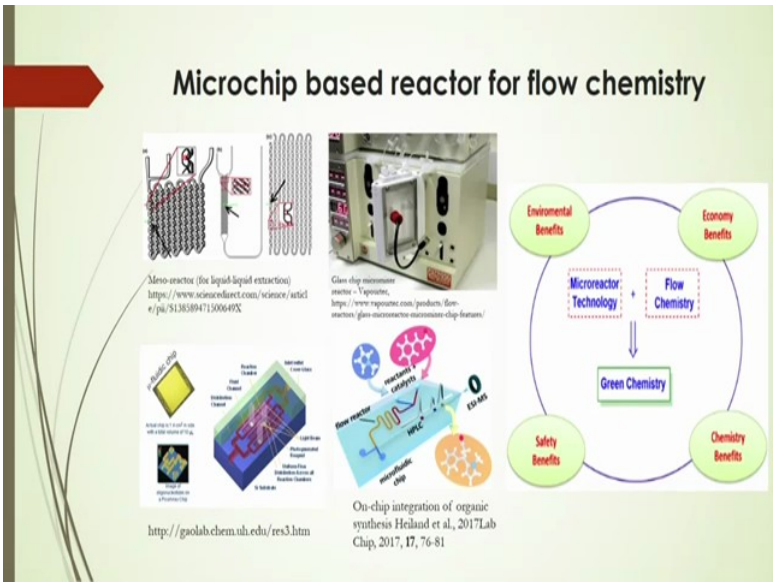

Now here we will see there are several microchip-based reactor for flow chemistry there. For the chemical synthesis there are several micro-reactors being used for getting higher yield of that process. And it is advantageous because you know it may give that environment and benefits. It may give the economic benefits. It may give that chemistry benefits, safety benefits also.

And ultimately these micro-reactor technology with this flow chemistry in the micro-reactor, it will give you that ultimate green chemistry where that environmental benefits, economical benefits even safety benefits you can expect to get. So this type of microchip-based reactor with the flow chemistry for chemical synthesis it will be beneficial for Green chemistry.

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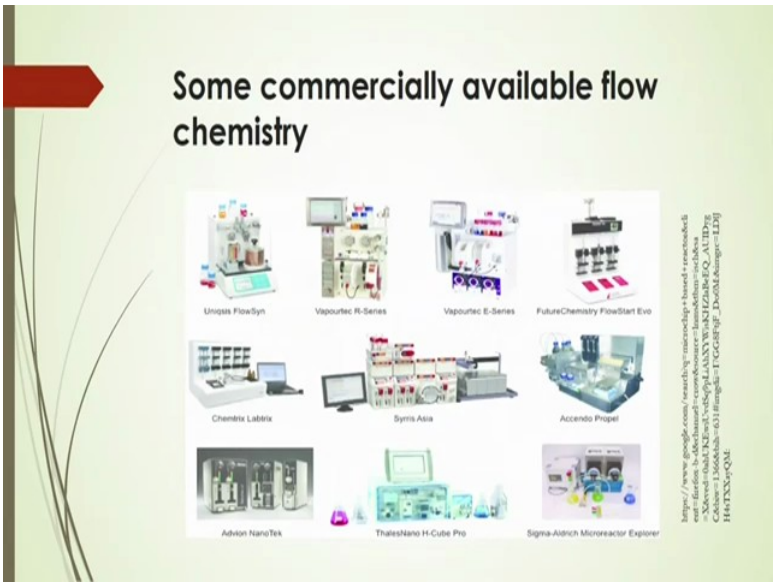

Some commercially available flow chemistry also are there like here it is given in the slides. Please go through the slides you can have some idea where different types of chemical synthesis in different types of micro-reactors for that technical process synthesis are being done commercially.

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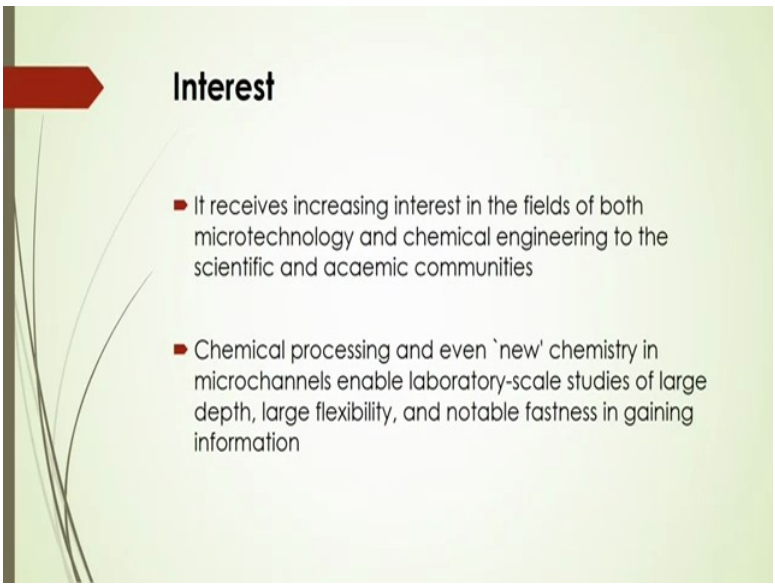

Now the question is that we know that micro-reactor how it is being defined and also what is that micro process technology, how it is being actually differed from that micro-reactor, all these things. Now interest is that we have to apply all those things micro-reactor for different chemical engineering process or other micro process systems. And day by day this application or research from this micro technology or micro-reactor system for micro process technologies are gaining to the scientific and academic communities.

And the chemical process even new chemistry in micro-channels enable, you will see that laboratory scale studies of large depth, large flexibility and notable fastness in gaining information that is why the research is going on everyday even every month you can issue several journals related to this topics of process intensification are published. And how we can say the interest is growing up day by day.

Because it gives you the several advantages over that conventional processes basically like Green chemistry system because nowadays the world is growing fast, in that case we have to develop the processes in such way that will be more sustainable, more greenery, more economic even that case more safety in issue. So that is why the interest is growing up day by day it micro process technology there to get that efficient way of process even more yield, more intensification of the process.

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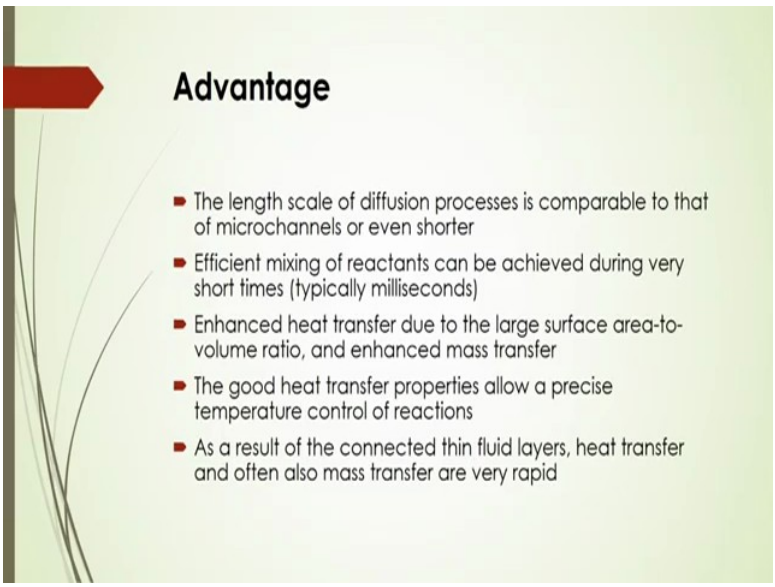

Now what are the advantages of that micro-reactor that we have to know that based on which that maybe interest is growing up day by day? Now the length scale of the diffusion processes is comparable to that of micro-channels or even shorter, so this is one aspect. Even you can get the efficient mixing of the reactants that can be achieved during very short times typically milliseconds.

Enhanced heat transfer due to the large surface area to volume ratio and also enhanced mass transfer there. Also you can get that good heat transfer properties that allow a precise temperature control of reactions. And also you will see that there will be a heat transfer and mass transfer that will be more rapid in this micro channel-based reactor there.

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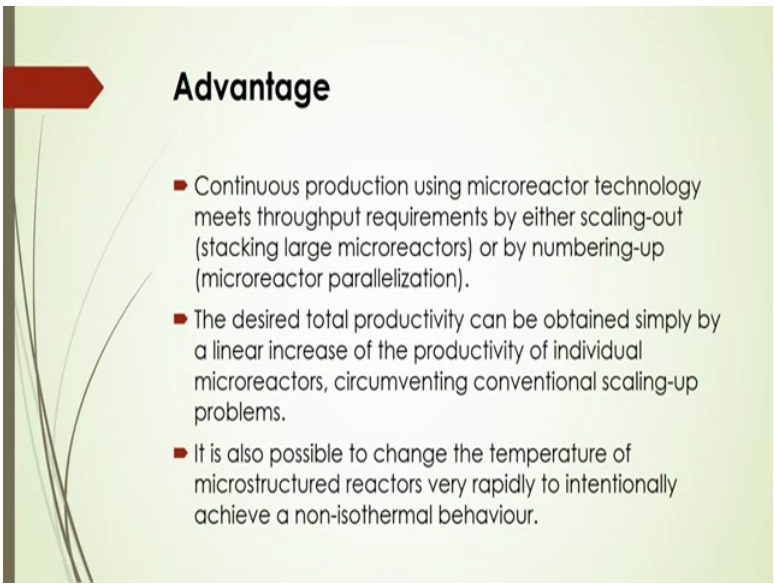

Also you can get that continues production by using this micro-reactor technology that meets throughput requirements by either scaling out that is stacking large of micro-reactors or by numbering up micro-reactors parallelization. And also it is possible to change the temperature of microstructure reactors very rapidly to internally achieve a non-isothermal behavior. And desired total productivity can be also obtained simply by a linear increase of productivity of individual micro-reactors even circumventing the conventional scaling up problems there.

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And the small hold-up reduces the damage potential of explosions or other hazardous states of male-operations there. Even you can get that operation at the kinetic limit, not superimposed by transport phenomena that may allow one to reach high space-time yields, so that the compact reactors and plants result. And selectivity is increased by suppressing that side reactions and by additional effect of precise setting of residents time the content of follow-up reactions that can be reduced their

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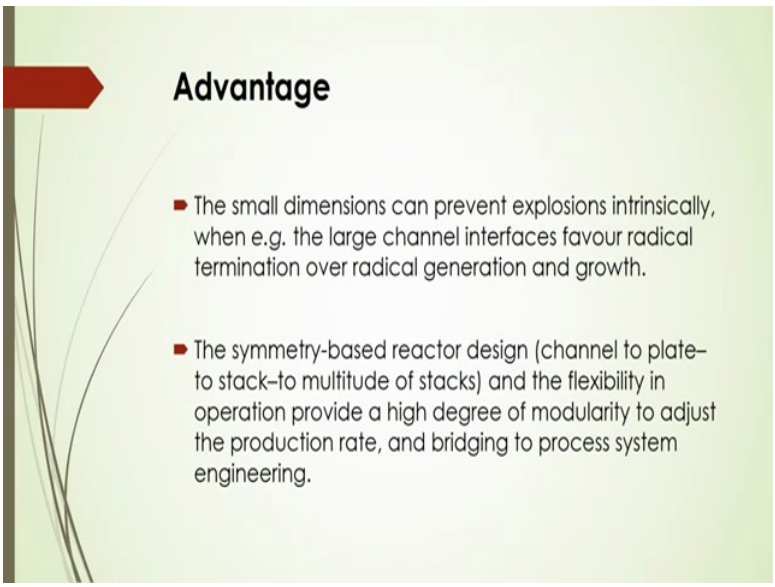

Also other advantages like the small dimensions can prevent explosions intrinsically and also you can say that the symmetry-based reactor design that is channel plate to stack to multitude of stacks and the flexibility in operation that provide a high degree of modularity to adjust the production time and also production rate and bridging to the process system engineering.

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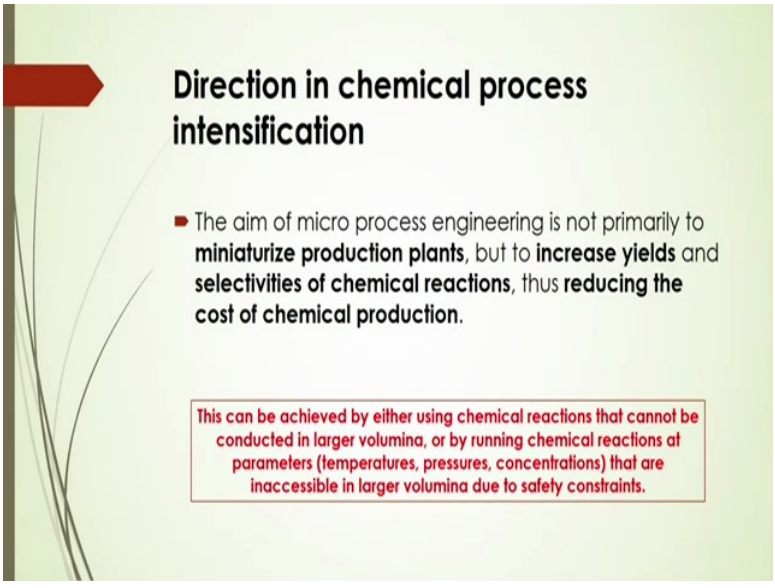

Now further direction in chemical process intensification. Actually the aim of that micro-process engineering is not primarily to miniaturize the production plants but you can say that it may utilize to increase yields and also selectivities of the chemical reactions and also you can use this further reduction of the cost of chemical production. So the main aim of that

micro process engineering is to miniaturize a production plant, increase yields, selectivities and also reducing the cost of the chemical production.

And this can be achieved by either using chemical reactions that cannot be conducted in large volumina or by you can say running chemical reactions at parameters like temperature, pressure, concentrations that are inaccessible in larger volumina due to the safety constraints.

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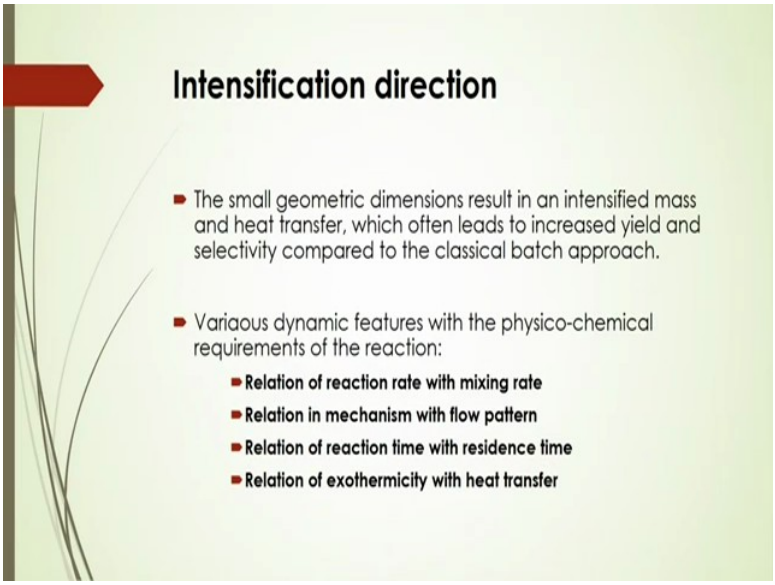

Now the small geometric dimensions that may result in an intensified mass and heat transfer which often leads to increase that yield and selectivity that is compared to the classical batch operation. Now various dynamic features to be considered when you will apply this micro-reaction technology. Now what are those dynamic features with the physicochemical requirements of the reaction that should be considered?

In that case what should be the relation of that reaction rate with mixing rate even relation in mechanism with flow pattern even relation of reaction time with residence time even relation of exothermic city with the heat transfer in this intensified way of heat and mass transfer in micro-process technology.

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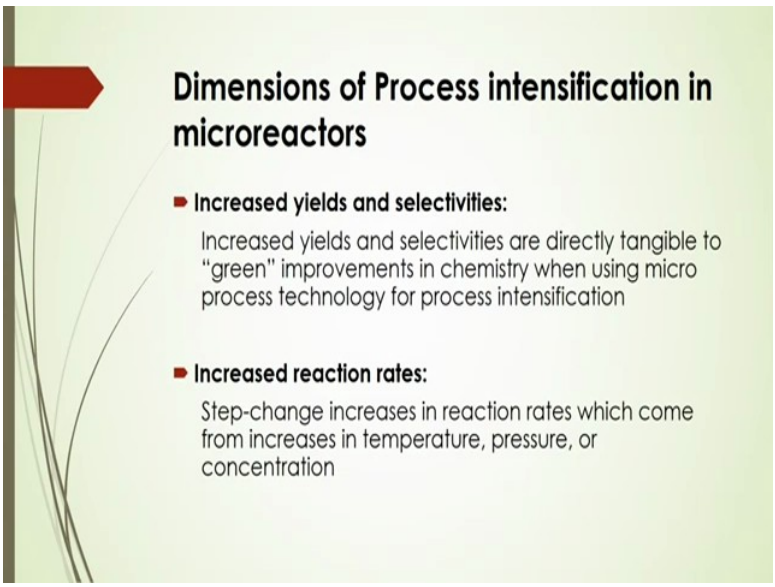

Now what are the dimensions of process intensification in micro-reactors? There are several aspects of process intensification in micro-reactors. Now it may be that increased yields and selectivities based on increase reaction time. Maybe based on reaction rate, maybe based on some safety issues, some economic consideration whether it is eco-friendly or not, different aspects of process intensification in the micro-reactor that is to be considered.

Like if you are considering increase yields and selectivities that increase yields and selectivities are directly tangible to green improvements in chemistry when using micro process technology for the process intensification. And in the case of increase reaction rates you can say that there will be some step change increases in reaction rates which come from increase in temperature, pressure or concentration.

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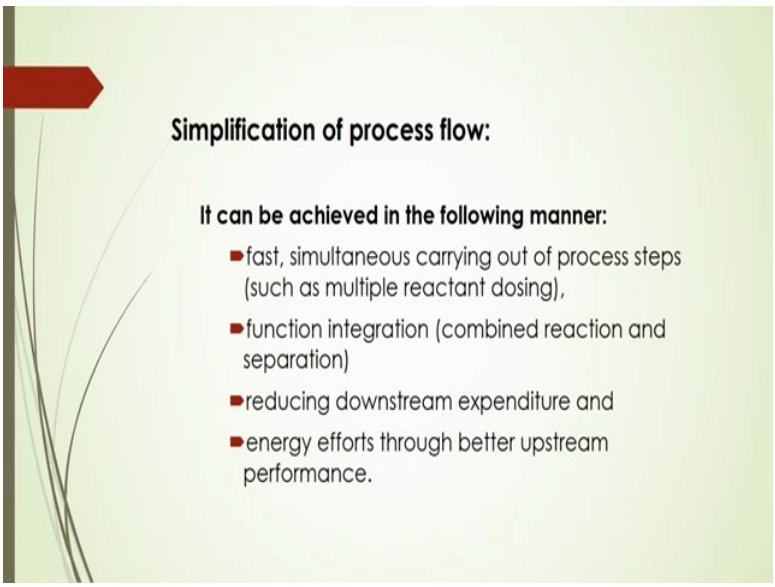

And also the simplification of the process flow you can get by the following manner like this here given in the slides. First you have to consider the simultaneously carrying out of the process steps such as multiple reactant dosing even how it will be function whether it will be integrating way or only single just entity there. So generally integration process is more favorable for that process intensification.

In that case combination of the reaction and separation will be done there, so that is why the simplification of the process can be done by integrating the system for the combination of reaction as well as reactive separation. Now reducing of downstream expenditure even energy efforts through better upstream performance are also those factors that can be considered for the simplification of the process flowing that micro process technology.

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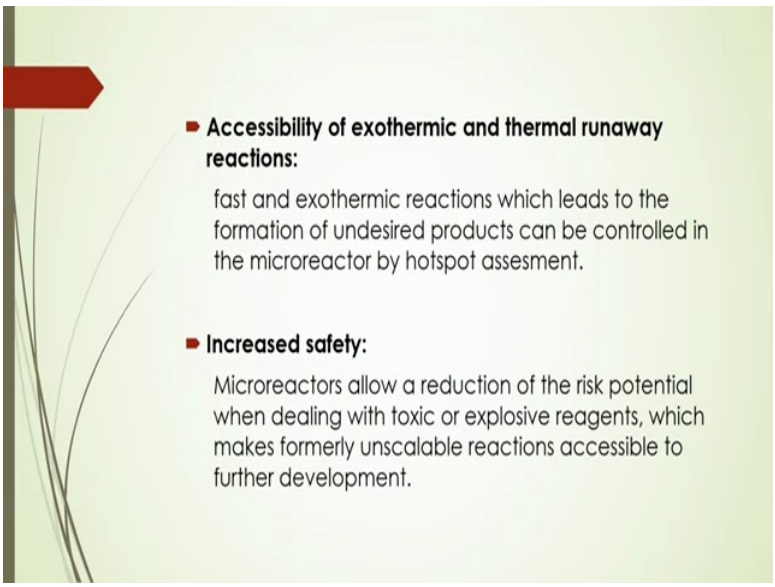

Now accessibility of exothermic and thermal runaway reactions are also important factors that to be considered for the process intensification macro process technology. In that case fast and exothermic reactions which leads to the formation of undesired products that can be controlled in the micro-reactor by hotspot assessment. So you have to consider that reactions in such way that whether that whatever heat is coming out that should be utilized in different ways. And also it may be controlled in such way that it may be distributed throughout the reactor just by having that intensified way of the flow characteristics to the channel-based reactor.

And also increased safety to be also considered in this process intensification with this micro-reactor system. So in that case micro-reactors may allow a reduction of the risk potential when dealing with the toxic or explosive reagents, which makes formally un-scalable reactions accessible to further development there.

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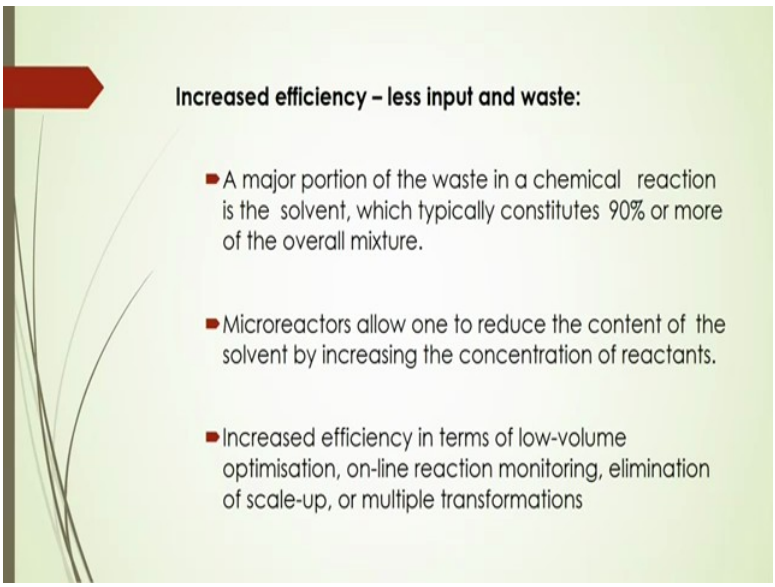

Now this micro-process technology for the process intensification, another important dimensions to be considered like how to increase that efficiency less input and waste. So in that case the major portion of the waste in a chemical reaction is a solvent, which typically constitutes 90 percent or more of the overall mixture and this micro-reactors that also allow one to reduce the content of the solvent by increasing the concentration of reactance.

Also you can say that the efficiency can be increased in terms of low-volume optimization in the micro-reactor. Even on-line reaction monitoring, elimination of the scale up our multiple transformations that can also be considered for that process intensification based on low-volume optimization even the on-line reaction monitoring.

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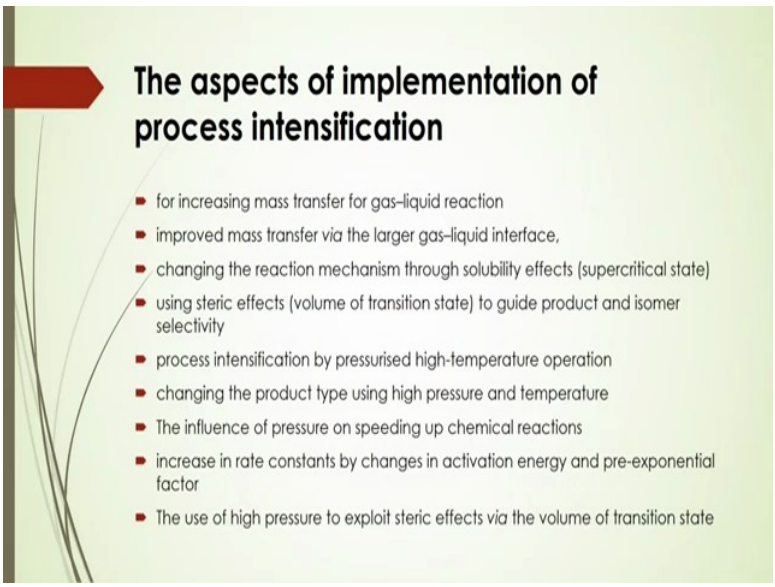

Now what are the aspects of implementation of that process intensification? What are the things that you can implement for the process intensification? Now for increasing the mass transfer of gas-liquid reaction that is one aspect of the implementation of the process intensification. How to improve that mass transfer via the last gas-liquid interface that is also another aspect?

Now changing the reaction mechanism through the solubility effects that also can be done and the reactor for getting the process intensification. Also using that steric effects there is volume of transition state to guide product and isomer selectivity and also you can get that process intensification by pressurized high-temperature operation.

We will discuss more about that high pressure and high-temperature system for the application of the reaction in the micro reactor system in the next lecture and also changing the product types using high pressure and temperature. Also there will be a certain influence of the pressure on speeding up of the chemical reactions and in that case increase in rate constants by changing in activation energy and also pre-exponential factor based on the temperature effect.

And the use of high pressure to exploit steric effects via the volume of transition state. So these are the several aspects of that implementation for that process intensification in the micro-reactor technology there.

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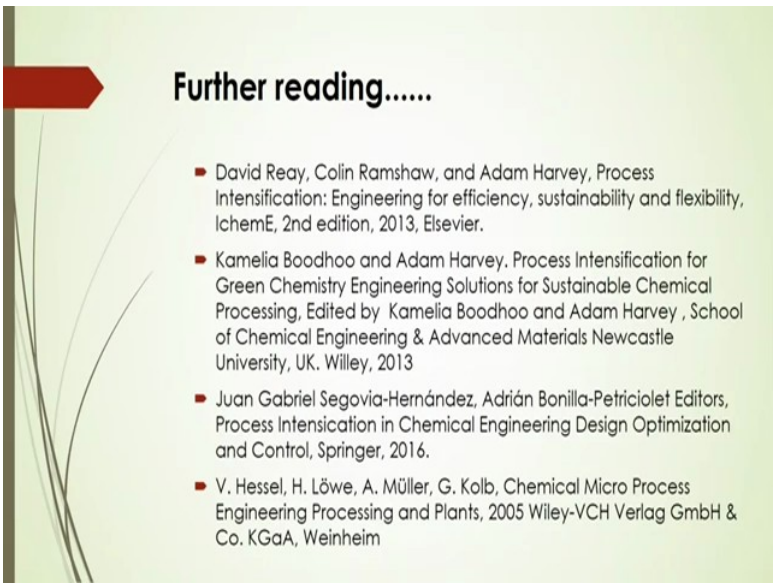

So we have discussed something that process intensification direction in the micro-reactor technology and what is that micro-reactor? And how it can be assessed based on that different process intensification directions that all we have discussed. So they are given some introductory information of that micro-reactor system. We will discuss more about that micro-reactor system with some applications in different chemical engineering processes where we can apply this micro-reactor system for intensification of the process.

So I would suggest you to go further about this micro-reactor system to know more about that micro-reactor system even micro process technology system. Basically you can go through this last a reference here Hessel in 2005 the book that is chemical micro process engineering, processing and plants I think these books will be more helpful for getting more information about the micro process technology.

So thank you for your attention.