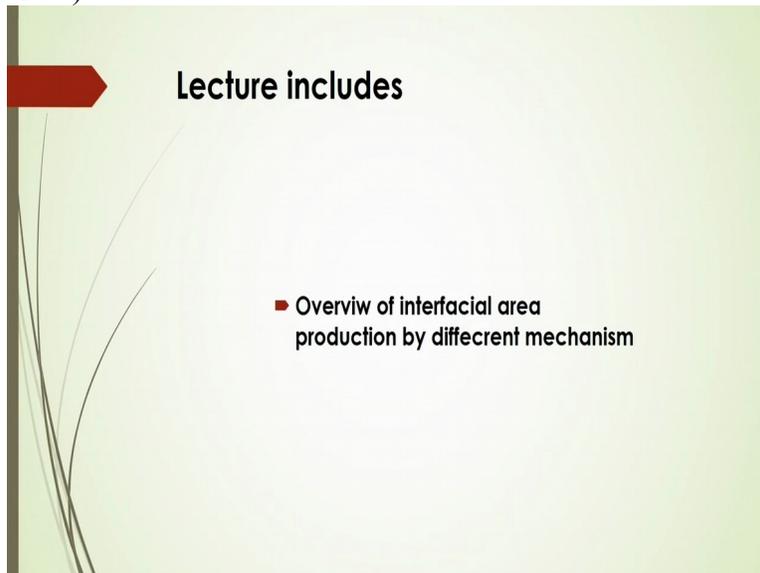


Chemical Process Intensification
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Module 8: Interfacial area based processes PI
Lecture 8.1: Overview of Interfacial area based processes

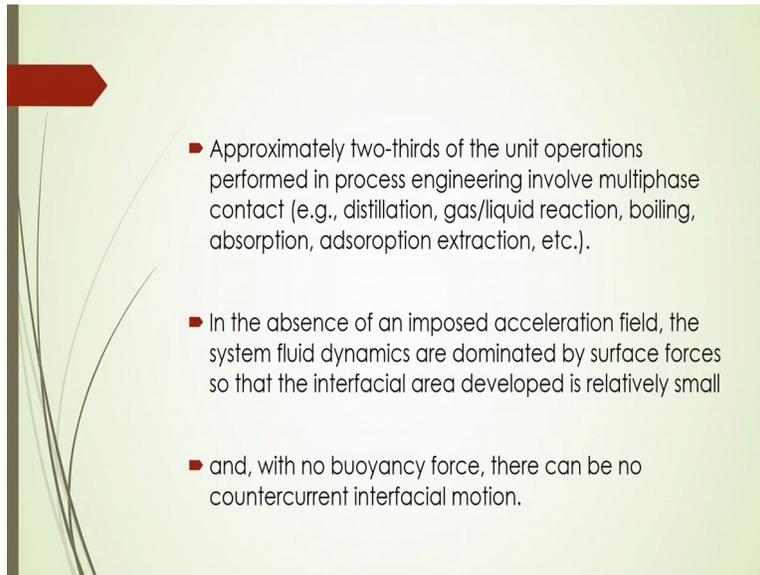
Yeah, welcome to massive open online course on Chemical Process Intensification. Here we start the module 8 regarding interfacial area based process intensification.

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Under this module, the first lecture will be regarding the overview of interfacial area based processes and also how to create that interfacial area based on different mechanism so that that interfacial area will be the governing factor for any process intensification.

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So as we know that approximately, two-thirds of the unit operations performed in the process engineering that involves multiphase contact like you know that distillation, adsorption, absorption, extraction, even some other chemical engineering processes where interface is the main actually path to actually transfer the one component from the one phase to the another phase. So in that case, there are several mechanism which may be actually imposed to generate this interfacial area in the multiphase systems. Now that multiphase systems may be that gas liquid operations, liquid-liquid operation, gas-solid operations and also gas-liquid-liquid operations and gas liquid-liquid-solid operations also.

So all those multiphase operations mainly depends on interfacial area because the chemical engineering processes mainly is governed by the mass transfer and heat transfer processes. So that mass transfer and heat transfer depends on this you know that specific interfacial area of the systems where that interface between the phases is created per unit volume. So and also whenever these interfaces will be formed, of course that one phase will be actually travelling as a dispersed phase and another phase will be as a continuous phase. So the interface will be between in that discrete phase and the continuous phase.

So like you know that if you apply some that absorption process of gases, that is if you consider the physical operations like that absorption of carbon dioxide gas in the liquid, so in that case to

transfer that carbon dioxide gas to the liquid, that you know it will be through the surface between that carbon dioxide gas and the liquid.

Now that you cannot actually do that or you cannot produce that enough interfacial area if you simply supply that carbon dioxide gas just flowing through the surface of the stagnant liquid there. So you may get some surface area but that may not be the intensified way. So to get that more interfacial area to absorb that carbon dioxide into the liquid through that interface, you have to think some other mechanism so that you can increase that interfacial area. So for that, what you have to do?

Either you can supply the gas through the liquid as a dispersed phase of gas bubbles. So if you produce gas bubbles through the liquid in which that carbon dioxide gas is absorbed, so in that case carbon dioxide gas bubbles whenever it will be produced in that liquid like I mean solution or sodium hydroxide solution, so in that case you will see that carbon dioxide gas should be dispersed as a dispersed phase of bubbles and if you are producing more number of bubbles, you will see that you will get more surface area, more interfacial area between the phases of liquid and carbon dioxide gas.

Now one bubble if you produce, there will be a surface area $4 \pi R^2$ whereas if you produce from the same volume of carbon dioxide, a large number of carbon dioxide gas bubbles then you can get more interfacial area instead of that having with a single bubble. So or you can think about that whatever you have produced without making a bubble, see what will be the intensification of that surface area production whenever it will be supplied horizontally over the liquid surface and if it is supplied just by creation of surface area just by forming of carbon dioxide gas bubbles and allowing to flow through the liquid.

So if you produce that more carbon dioxide gas bubbles through the liquid and if you allow it for flowing, you see what are the advantages? So advantages is that here you can get more interfacial area compared to that, just simply moving that gas through the horizontal liquid surface in a pool of liquid or over the pool of the liquid. Now in a pool of the liquid, if you supply more bubbles, the advantage is that more surface area you can get as well as if you control that bubble for flowing for longer time in the liquid, then you can get more mass transfer also.

So you can intensify the mass transfer process based on the increase of surface area as well as what is that? Residence time of the bubbles there. Now if you supply that gas bubbles from suppose from the bottom of a pool of liquid by a certain mechanism, maybe gas distributor or other, so in that case you will see due to the buoyancy effect of the bubbles, it may go up immediately if its size is very large but if its size is smaller, even finer, even micron in size, even nano in size, what will happen?

You can get more surface area as well as more residence time of the bubbles because smaller bubbles will give you the higher residence time. Whereas larger bubbles will give you the less residence time in the liquid. So just by creating that surface area in such a way that more surface area whenever you are producing just by making a that bubbles or maybe liquids droplets, in that case you may get more surface area as well as residence time. So both the effects simultaneously will give you the better performance of the mass transfer or any other chemical engineering process based on mass transfer.

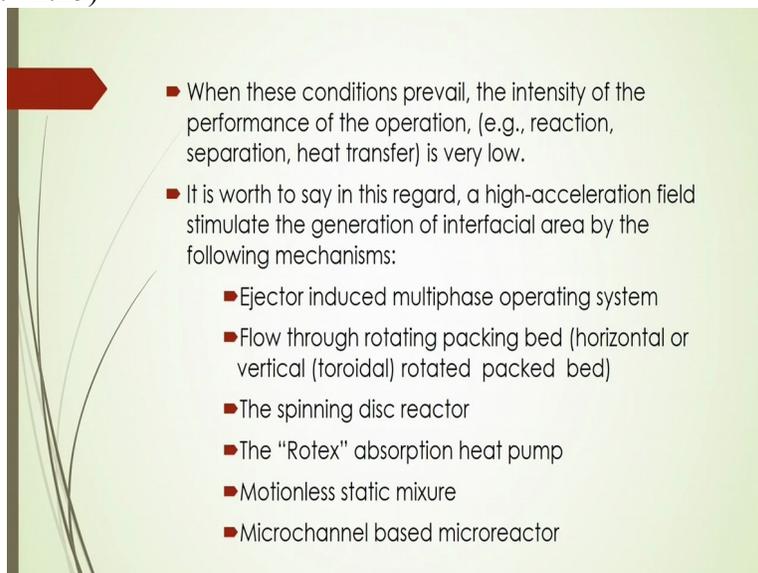
Even you may expect the intensification of the heat transfer also by getting more surface area through which that heat will be transferred. So this is the mechanism or simple mechanism by which you can get more interfacial area and residence time. But there are several other mechanisms by which you can generate more surface area between the phases and residence time also that you can control so that you can get more mass transfer, more efficiency of the processes. So that is why, we have to think about that what will be the mechanism for that that we can produce more surface area there.

Now if you consider that the imposition of acceleration field, in that case suppose if you produce that bubbles, there maybe certain force is applying there based on which that bubble is produced, interfacial area is produced. Maybe by that by forcing that liquid through the small geometry and there will be a certain pressure drop between that you know the **two** sections, then you may expect that due to that pressure differences, there will be formation of bubbles. So here what happened that we are just supplying some liquid from a certain location **to another** location through a constriction just by generating the acceleration field of that fluid. So this is one mechanism.

But in case of if you are not imposing that acceleration field, the system fluid dynamics may be dominated by the surface force is there so that the interfacial area development will be relatively small and in that case, with no buoyancy force there can be no counter current interfacial motion there.

So in this way you can think that some imposition of the acceleration field like you know that shear stress, the fictional pressure, you know that maybe that ultrasound, maybe some ejector system inducing the gas and entraining into a liquid, that is also another mechanism. Maybe, centrifugal force, that may create that surface area.

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- When these conditions prevail, the intensity of the performance of the operation, (e.g., reaction, separation, heat transfer) is very low.
- It is worth to say in this regard, a high-acceleration field stimulate the generation of interfacial area by the following mechanisms:
 - Ejector induced multiphase operating system
 - Flow through rotating packing bed (horizontal or vertical (toroidal) rotated packed bed)
 - The spinning disc reactor
 - The "Rotex" absorption heat pump
 - Motionless static mixture
 - Microchannel based microreactor

So to actually intensify the performance of the operation, okay like reaction separation, heat transfer, mass transfer, in that case you have to think about the application of high acceleration field to simulate for the generation of the interfacial area by certain mechanism. What are those mechanisms that, I told already that maybe ejector induced multiphase operating system, we will be actually discussing in details later on also, the next lecture we will becoming that ejector induced multiphase operating system, how actually that interfacial area is formed.

In this case you will see that some liquid jet will be produced by supplying the liquid through the nozzle and it will be actually passing through an ejector system and whenever the liquid jet come through the ejector system, that liquid jet may suck some gas from the atmosphere or from other sources and then it will entrain or penetrate that gas into the pool of liquid.

And during that penetration, you will see there will be a surface breakup of that pool of liquid and entrainment of the gas as a dispersed phase of bubbles. And then that bubbles will be moving downward by downward movement of that liquid jet and it will be flowing through the tube or column so that the formation of bubbles which will give you the interfacial area as well as whenever it will be moving downwards, at the same time the buoyancy force will try to move it up and there will be a certain condition at which that this upper buoyancy force and downward liquid momentum may balance it and it may reside for longer time in the column or in the system or in the unit.

So in that case, you may get more residence time of that gases in the liquid so that through the interface of that phases, there will be a transfer of some components from the one phase to the another phase. So this is the mechanism of that ejector induced multiphase operating system by which you can create that interfacial area and its application for different chemical engineering processes. So simply that gas absorption may happen here. Even sometimes liquid-liquid extraction you can do here. So this is one mechanism.

And also flow-through rotating packed bed is also another important mechanism by which you can create more surface area. In that case, it may be vertical, vertical rotation that is called toroidal, even sometimes it will be horizontally rotating packed bed. And the spinning disc reactor also, that is important. Some you know that absorption heat pump that is called Rotex, motionless static mixture, that is also another mechanism by which you can produce more interfacial area, microchannel based micro-reactor just producing that interfacial area and that making a plug flow and then you can get the advantages of the reactions were there based on that interfacial area.

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In motionless static mixture

- Mixing in a motionless mixer is rapid and is achieved by the action of splitting and twisting of the flow by the mixer elements.
- Energy dissipation rates are high, with typical values between 10 and 1000 W/kg, compared to an upper limit of around 5 W/kg in conventional equipment, such as stirred tanks
- These large dissipation rates give rise to much higher mixing rates for intensified mixers when compared to stirred tanks.



Ref:
<https://www.pickford.com/motionless-mixers.html>

Now let us consider that motionless static mixture. In that case, the phases are mixed in the mixer and this mixture will be so rapid and in that case mixing can be achieved by action of splitting and twisting of the flow by you know that mixer elements as shown in figure here. And you see that there will be some energy dissipation rate and it should be very high because you are applying this energy to split and twisting the flow by the mixture elements. And by splitting and twisting of the flow, you can have that formation of interfacial area there between the phases.

In this case, you will see that energy will be very high. It maybe, this is 10 to 1000 watt per kg and also you can say that some other the convenient equipment can be used to produce that interfacial area but that will not be comparable with this type of static mixture because this static mixture may give you that maybe a higher energy consumption but it may give you that more interfacial area compared to the other equipment where less energy is consumed like as a stirred tanks. Now this large dissipation rates may give rise to the much higher mixing rates for intensified mixers when compared to the stirred tanks.

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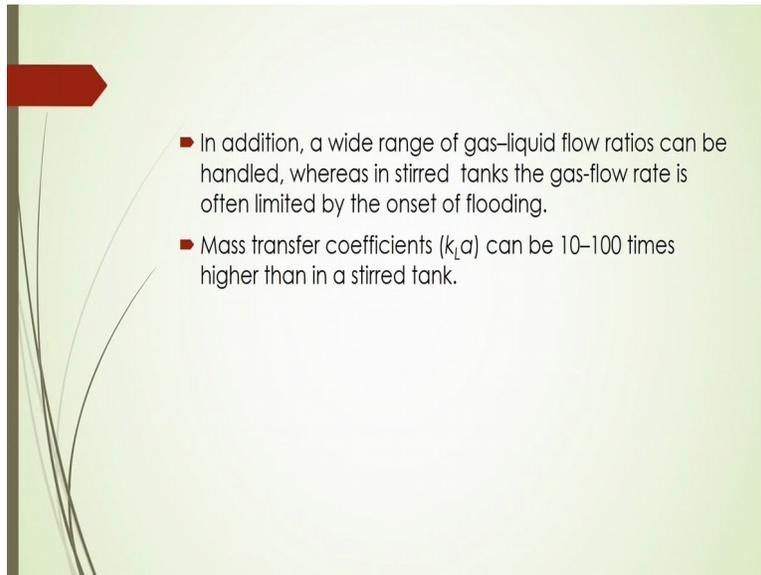


Now when two phases are mixed together, like gas-liquid, immiscible liquid-liquid, in that case, a fine dispersion of the bubbles or drops in case of liquid-liquid phases and high specific interfacial area can be produced because of that intense turbulence, that is created by that mixing elements inside the static mixture. So there will be high turbulence and also there will be shear that liquid element with that mixing elements and based on which that you can get that more surface area just by forming bubble and droplets.

That is why, in this case you will see resistance to the interface mass transfer is considerably smaller than in conventional equipment here. So you are getting you will see that more finer interfaces, that is very thin-layer between the liquid and that mass transfer will be through the thin film of region of that interfaces. So that is why this the resistance of the interface for the mass transfer will be less compared to the other equipment where that mass transfer is taking place through the interface.

So we are getting here very interesting point here that bubble drops may give you that resistance to the interface mass transfer relatively smaller compared to the other equipment. So this is one of the important mechanism by which you can create the interfacial area between the phases. In addition, a wide range of gas liquid flow ratios can be handled here whereas in stirred tanks, the gas liquid flow rate is often limited by the onset of flooding.

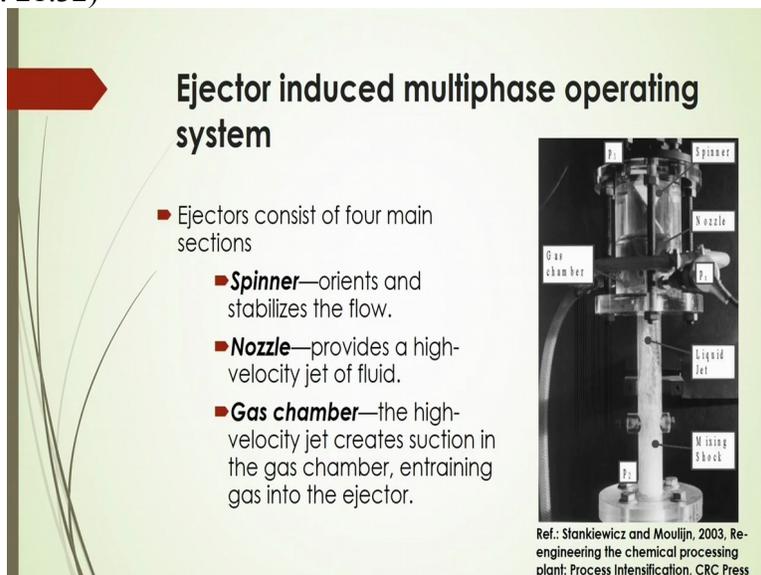
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- In addition, a wide range of gas-liquid flow ratios can be handled, whereas in stirred tanks the gas-flow rate is often limited by the onset of flooding.
- Mass transfer coefficients ($k_L a$) can be 10–100 times higher than in a stirred tank.

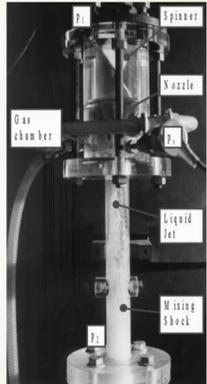
So if you are applying that stirred tank reactors instead of that static mixer, so you may get that flooding condition in the stirred tanks. And also in case of static mixture oriented interfacial area production may give you the higher mass transfer coefficient. It may be within the range of 10 to 100 times higher than a stirred tank reactor. So we are getting that one mechanism here just the by static mixture, how to produce that surface area for the process intensification.

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Ejector induced multiphase operating system

- Ejectors consist of four main sections
 - **Spinner**—orients and stabilizes the flow.
 - **Nozzle**—provides a high-velocity jet of fluid.
 - **Gas chamber**—the high-velocity jet creates suction in the gas chamber, entraining gas into the ejector.



Ref.: Stankiewicz and Moulijn, 2003, Re-engineering the chemical processing plant: Process Intensification, CRC Press

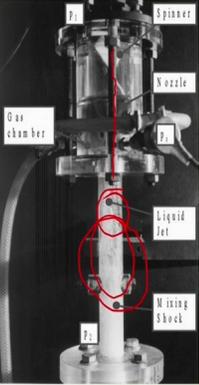
Now we have already told something about that ejector induced multiphase operating system there. In this case, the figure shown, we are thankful to the investigator of you know that or you

know report by Stankiewicz and Moulijn. In 2003, they have given this you know that ejector induced multiphase operating system where it consists of 4 main sections. One is the spinner, that is orients and stabilises the flow. Here as shown in figure, it is shown and nozzle there I think it is there nozzle.

And this nozzle, it provides a high velocity jet of the fluid. Gas chamber, the high velocity jet that may create suction in the gas chamber that entrains gas into the ejector. So this type of ejector system here you will see, due to the pressure difference and sucking the gas into the pool of the liquid and then passing from the higher pressure to the lower pressure, and you will see that there will be a you know that pressure due to this pressure differences, there may be a formation of that bubbles if it is gas liquid operation, droplets if it is you know that liquid-liquid operation then you can get this type of that system for the interface production.

And then, after production of that interfacial area, that is by making that bubbles, it may leave that gas chamber and the liquid jet that attaches itself to the mixing tube wall, resulting in a rapid dissipation of kinetic energy and creating an intensive mixing zone, that known as mixing shock region there.

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- **Mixing tube**—on leaving the gas chamber, the liquid jet attaches itself to the mixing tube wall, resulting in a rapid dissipation of kinetic energy, creating an intensive mixing zone known as the *mixing shock* region.
- High turbulence in this region breaks up the gas, producing a fine dispersion of bubbles and consequently a large interfacial area for mass transfer.
- Ejectors and motionless mixers have similar mass transfer performance at a given gas-to-liquid flow ratio and energy input

Ref.: Stankiewicz and Moulijn, 2003, Re-engineering the chemical processing plant: Process Intensification, CRC Press

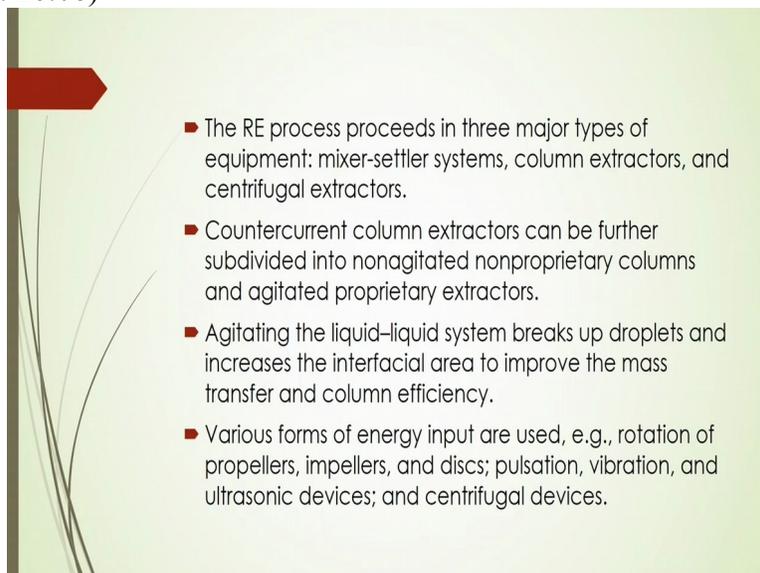
So whenever it will be released from that, you know that ejector system after sucking, you will see that there will be a zone in the tube here in this location here in this tube, these locations you will see there will be a gas liquid mixing. Intense mixing will be there and from this jet from

here, whenever it will be plunging in the pool of the liquid here, at this you know that pressure differences and just breaking of that pool of the liquid and entraining the gas into the liquid and making that formation of the bubbles and formation of the interface, you will see that bubbles will be there in the mixing zone in the tube.

And this mixing zone will give you that intense mixing of the phases of that gas bubbles in the liquid due to the high kinetic energy dissipation that is supplied by the liquid jet as per kinetic energy of the liquid jet. So this you know that mixing zone, it is called intense mixing zone, maybe referred as a mixing shock region. So in this case high turbulence is created and based on that high turbulence and the you know that high kinetic energy distribution in this region, the breakup of that permuted bubbles will be there and producing that fine dispersion of the bubbles and consequently a large interfacial area will be generated which will be more beneficial for the mass transfer.

Now if you compare that ejectors and motionless mixtures, you will see it may be that similar mass transfer performance at a given gas-liquid flow ratio and energy input.

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- The RE process proceeds in three major types of equipment: mixer-settler systems, column extractors, and centrifugal extractors.
- Countercurrent column extractors can be further subdivided into nonagitated nonproprietary columns and agitated proprietary extractors.
- Agitating the liquid-liquid system breaks up droplets and increases the interfacial area to improve the mass transfer and column efficiency.
- Various forms of energy input are used, e.g., rotation of propellers, impellers, and discs; pulsation, vibration, and ultrasonic devices; and centrifugal devices.

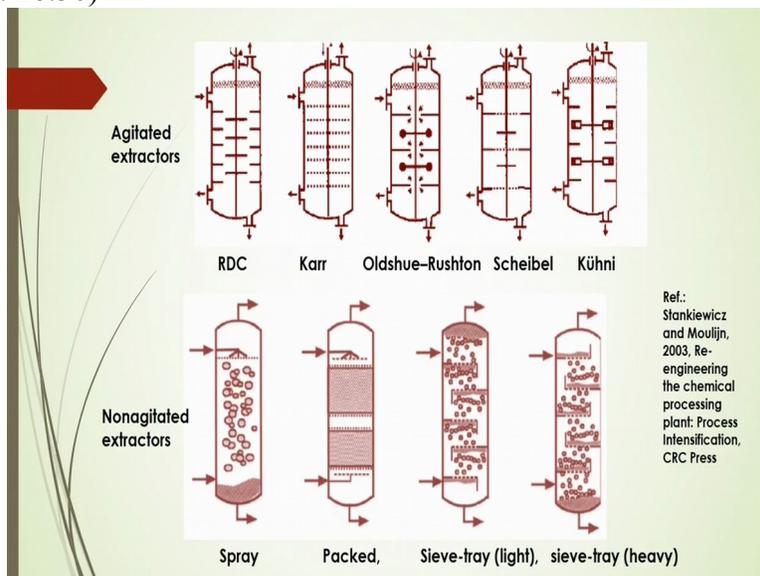
And the reaction engineering process that proceeds in 3 major types of the equipments like mixer-settler systems, column extractors and centrifugal extractors and where, you can produce that interfacial area based on this static mixture, even you know that ejector system and also you know that some other centrifugal field where you can apply those things for the intense mixing,

for the better mass transfer, for the extraction process and also you know that combination of the you know that reaction and extraction, both also there maybe at a simultaneous condition. Now countercurrent column extractors can be further subdivided into non-agitated nonproprietary columns and agitated proprietary extractors.

So this is also another important point to be actually noted here, sometimes you will see that some systems will be agitated, some systems will be non-agitated. Like static mixture, that is you know that it is non-agitated system where as the liquid or ejector induced or jet induced gas-liquid operation are called agitated systems and they are you know that in agitating system, that the liquid-liquid systems would be broken up into a finer droplets or finer bubbles that may increase the interfacial area to improve the mass transfer and also if its reacted efficiency.

Various forms of energy inputs may be imposed for the formation of that interfacial area like rotation of the propellers, impellers, and discs, pulsation mechanism, vibration also it may be there, even ultrasonic device, even centrifugal device also may be used for that creation of interfacial area for the better mass transfer.

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Here you will see some figures as per that Stankiewicz and Moulijn in 2003 when they were actually discussing about that re-engineering of the chemical processes in the plant and they have published those things in a book like as a re-engineering chemical processing plant. In that, in their book they have actually refuted that these agitated extractors and the non-agitated extractors

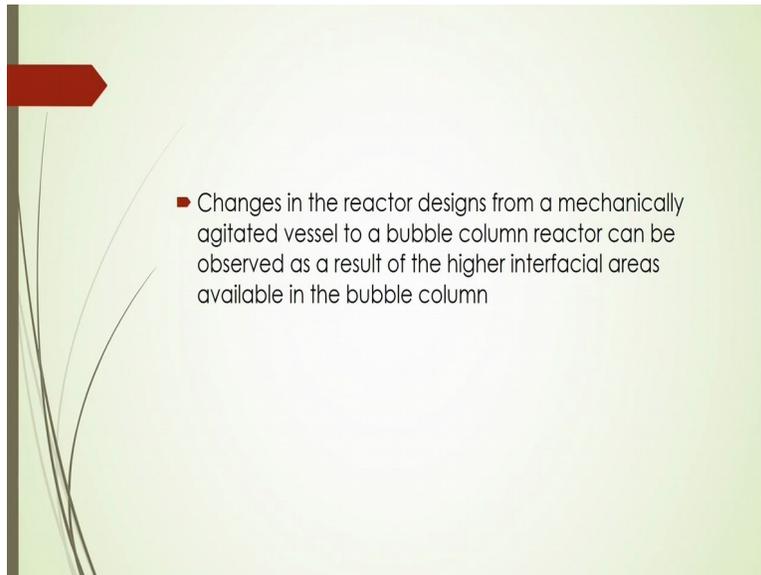
there. So where agitated extractors may be that like rotating disc column here, even may be some other column like vibrating column and also that Kuhni rotating extractor column, Scheibel extraction column, you know Oldshue-Rushton that extraction column, Korr extraction column, those are agitated extractors where you can produce more interfacial area based on that rotation.

And for non-agitated extractors like that static mixture, even spray column where from the nozzle that droplets will be sprayed and it will be allowed to flow in a certain direction or vertically upward or that downward. And during that flow and residence time of that droplet, there may be a mass transfer between the phases of that droplet and other liquid. And also packed bed here in that case, you know that the liquid will be spread through the bed of packing material to get the uniform distribution of the liquid throughout the bed and so that it may get the contact with the solid surfaces well in good condition.

But there may be some advantage-disadvantage of those packing column, packed bed systems and in that case, that maybe sometimes it is being intensified to avoid all those disadvantage there, sometimes now it is that rotating packed bed is coming, even it may be horizontal or vertical, toroidal packed bed, that may give you the better performance compared to the conventional packed bed system.

Even sieve tray you will see there you know that distribution of the vapor or gas through the that plate or tray through which there will be a porous plate of those you can get that formation of bubbles or droplets through that tray and that droplet will actually produce that more interfacial area and get the intensification of the mass transfer chemical engineering processes.

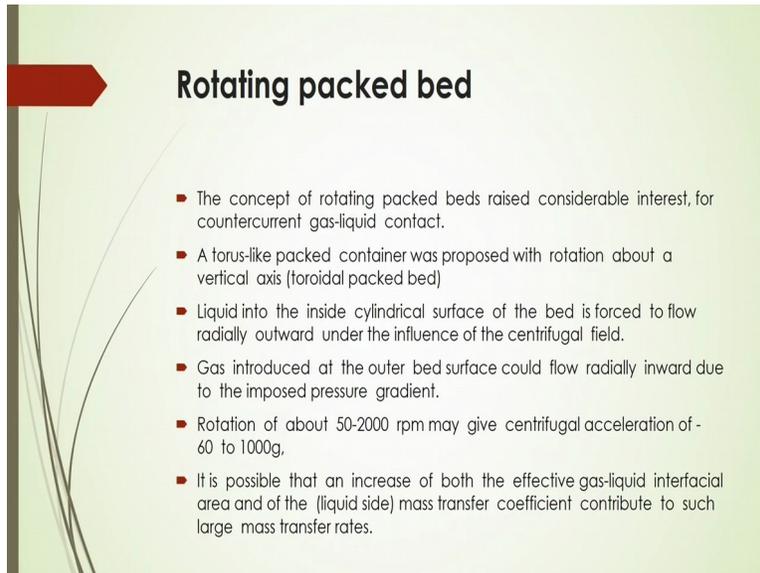
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Now the changes in the reactor design may also give you the sometimes better performance of that chemical engineering processes based on the mass transfer and if you change that reactor design from a mechanically agitated vessel to a suppose bubble column reactor where gas is distributed from the bottom of the column through the distributor as a this 1st phase of bubbles in a continuous liquid or in a stagnant or in a pool of liquid you can say, that can be observed that as a result of the higher interfacial area that is available in the bubble column that you can apply this you know that high interfacial area for the increase of that is efficiency of the mass transfer and consequently the chemical engineering process performance.

So that is why, the design of that equipment you can think in novel way how to design that equipment to get the better way of mass transfer just by creating the you know that more interfacial area and also case to case where that residence time will be required as low or high, so accordingly you can device, you can design different types of you know that column or reactor to produce that interfacial area.

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Rotating packed bed

- The concept of rotating packed beds raised considerable interest, for countercurrent gas-liquid contact.
- A torus-like packed container was proposed with rotation about a vertical axis (toroidal packed bed)
- Liquid into the inside cylindrical surface of the bed is forced to flow radially outward under the influence of the centrifugal field.
- Gas introduced at the outer bed surface could flow radially inward due to the imposed pressure gradient.
- Rotation of about 50-2000 rpm may give centrifugal acceleration of -60 to 1000g,
- It is possible that an increase of both the effective gas-liquid interfacial area and of the (liquid side) mass transfer coefficient contribute to such large mass transfer rates.

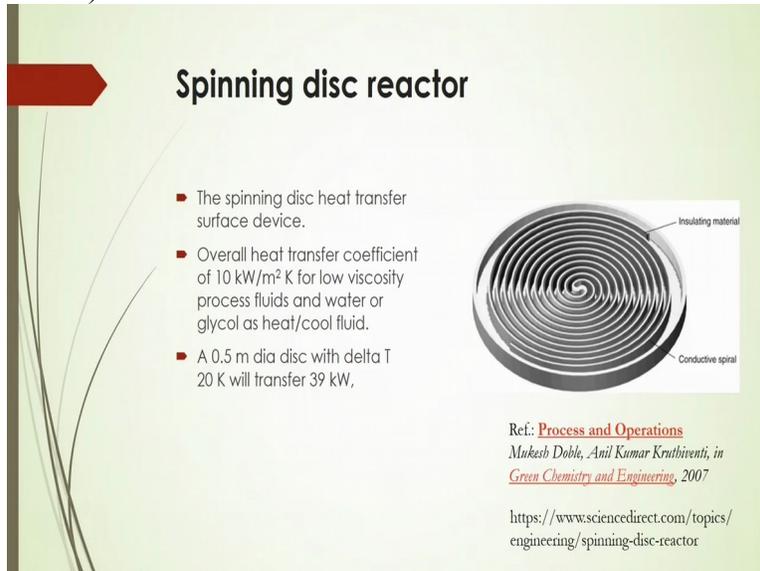
Now I told that there will be certain that disadvantages of that conventional packed bed. Now to overcome all those these that sometimes the concept of rotating packed beds are coming and it raised considerable interest for countercurrent gas liquid contact. In that case, torus-like packed container was 1st proposed in UK with rotation about a vertical axis. That is called toroidal packed bed. And in that case, in a patent that it is given that liquid into the inside cylinder surface of the bed is forced to flow radially outward under the influence of the centrifugal field.

And whatever gas is introduced at the outer bed surface, that maybe flow radially inward due to the imposed pressure gradient and also rotation of this column may give the advantages of the formation of this interfacial area and also distribution of the liquid through the column and so that maximizing the utilisation of the liquid to get contact to the gas and also solid surfaces. So in that case, rotation maybe of about 50 to 2000 rpm that may give this centrifugal acceleration of the 60 to 1000 g. g means here gravitational acceleration here.

Now it is possible that an increase of that both the effective gas liquid interfacial area and of the liquid side mass transfer coefficient, that may contribute to such a large mass transfer rates. So this is the advantage for that rotating packed bed. Whereas horizontal rotated packed beds also nowadays is coming. In this case, Serata and Hoshaka in 1991, they have applied this you know that rotation of the packed bed horizontally to get that more you know that efficiency of the that chemical engineering process.

In that case, they have applied some biological treatment of wastewater and in that case, they have actually used that or they have designed that rotating packed bed which will be partially immersed in liquid while the rest is exposed to the atmosphere. Now in this case, you may get that more uniform liquid distribution in the packing under well-controlled conditions. So this advantage over that vertical rotated packed bed.

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Spinning disc reactor

- The spinning disc heat transfer surface device.
- Overall heat transfer coefficient of $10 \text{ kW/m}^2 \text{ K}$ for low viscosity process fluids and water or glycol as heat/cool fluid.
- A 0.5 m dia disc with delta T 20 K will transfer 39 kW,

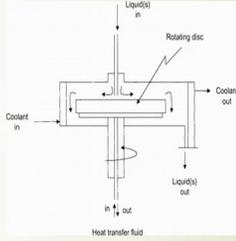
Ref.: *Process and Operations*
Mukesh Doble, Anil Kumar Kruthiventi, in
Green Chemistry and Engineering, 2007
<https://www.sciencedirect.com/topics/engineering/spinning-disc-reactor>

Other important mechanism to create that surfaces to get more contact to that phases of the solid surfaces, catalyst surfaces with the liquid or gas, in that case the spinning disc heat transfer surface also important through which there will be the transfer of heat through the surface. In this case, overall heat transfer coefficient is about 10 kilowatt per meter square K for low viscosity process fluids and water for you know or you can use glycol as a heat or cool fluid or other fluid also you can use, this type of that is spinning disc reactor, this is a spiral reactor.

And here, see, through that channel, there will be a **flowing** of cooling liquid to that transferring of heat from that higher heated element to the lower heated element. So in this case, the heat transfer from the higher temperature to the lower temperature can be done by this you know that spinning disc reactor. In this case, very interesting that there may be secondary flow will be produced and which will give you that more that transfer processes there. And generally you know that 0.5 meter diameter disc with a delta T that is of 20 K, that makes temperature difference of 20 K, may transfer 39 kilowatt as per actually this **double**. In 2007 report, they have

actually given this idea for this spinning disc reactor for the process and operations in intensified wave.

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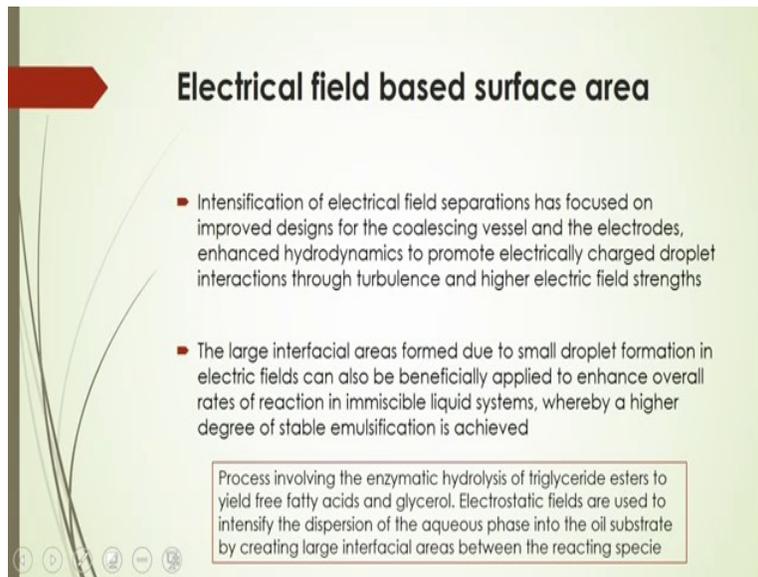


- Spinning disc reactors (SDR) are operated horizontally or vertically and are mounted on a rotating axle.
- Liquid is fed near the center and flows across the surface of a spinning disc under the influence of centrifugal force.
- This force stretches and spreads the film.
- The thin liquid film allows for high rates of mass transfer so that it favors unit operations such as absorption, stripping, mixing, and reactions.
- Residence time on the disc is in the range of 0.1 to 3 s.

That, other way that spinning disc reactors are operated generally horizontally or vertically and are mounted on a rotatory axle and in that case liquid is fed near the centre and flows across the surface of the spinning disc under the influence of centrifugal force. And this force may be stresses and spreads to the film and this film whatever it is produced, it is a liquid thin film you can say, it may allow you know that for high rates of mass transfer so that it favors unit operations such as absorption, stripping, mixing and reaction just by getting more contact of the liquid with the you know that surface area just by uniform distribution of the liquid and also getting that more uniform mixing of the phases and also that interfacial transfer.

So in this case, residence time on the disc, maybe the range is of 0.1 to 3 seconds as per their observation.

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Electrical field based surface area

- Intensification of electrical field separations has focused on improved designs for the coalescing vessel and the electrodes, enhanced hydrodynamics to promote electrically charged droplet interactions through turbulence and higher electric field strengths
- The large interfacial areas formed due to small droplet formation in electric fields can also be beneficially applied to enhance overall rates of reaction in immiscible liquid systems, whereby a higher degree of stable emulsification is achieved

Process involving the enzymatic hydrolysis of triglyceride esters to yield free fatty acids and glycerol. Electrostatic fields are used to intensify the dispersion of the aqueous phase into the oil substrate by creating large interfacial areas between the reacting species

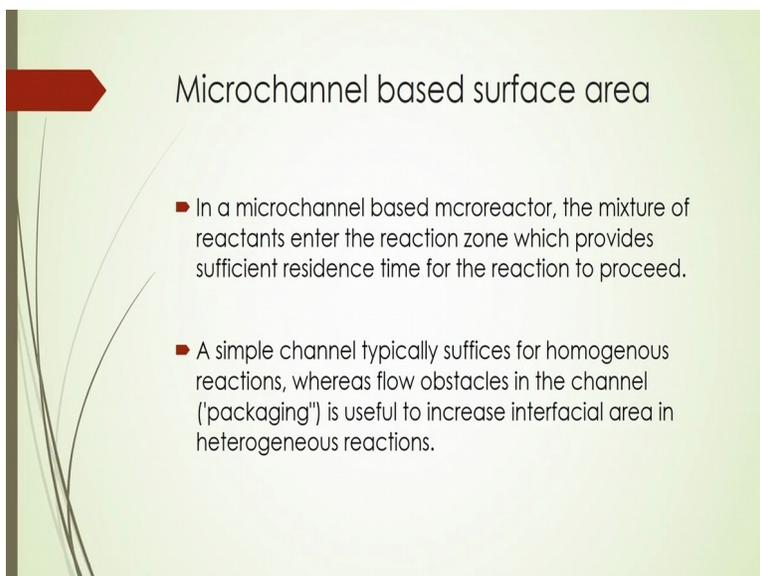
Now electrical field based surface area, also very important there that mechanism also are nowadays very interesting, or focusing by the you know that various research organisations to use that electrical field for the separation processes just by producing that the more interfacial area, just by interacting of the fluid element and also you can say that contacting of the phases just by this electrical field. So in this case, intensification of the electrical field separations has focused on improved design for the coalescing vessel and the electrodes.

That enhanced hydrodynamics to promote electrically charged droplet interactions through turbulence and higher electric field strength. And the large interfacial areas that forms due to small droplet formation in electrical fields, that can also be beneficially applied to enhance the overall rates of reaction in immiscible you know that liquid systems whereby a higher degree of stable emulsification is achieved there. So in this case, some process that involves the enzymatic hydrolysis, I think you know that enzymatic hydrolysis of triglyceride esters, that may give you that free fatty acids and also glycerol.

So in that case electrostatic fields are used to intensify the dispersion of the aqueous phase into the oil substrate by creating large interfacial areas between the reacting species. Another important mechanism to create the surface area, it is called that microchannel based surface area. Already we have discussed in our previous module that microchannel based monolithic reactor where how that interfacial area is being produced by making that slug flow of liquid and gases

and how that mass transfer is being happened through that interfaces of the gas and liquid in the monolithic catalyst bed reactors.

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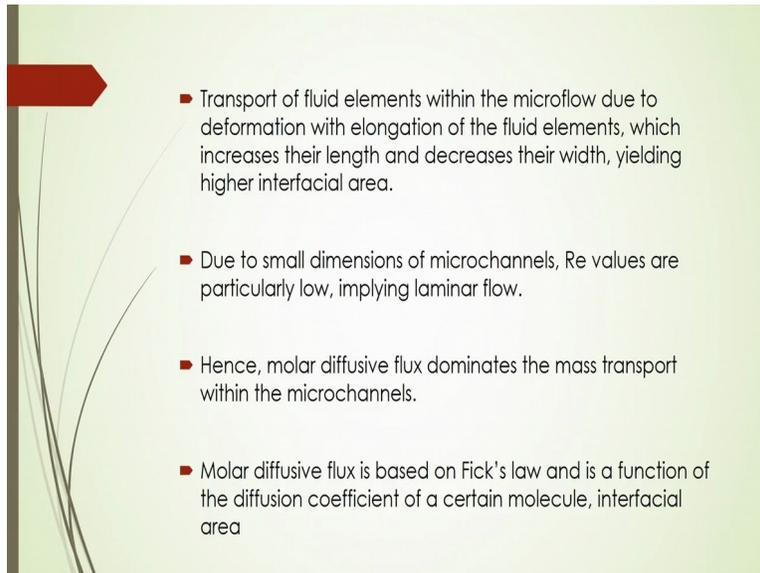


Microchannel based surface area

- In a microchannel based microreactor, the mixture of reactants enter the reaction zone which provides sufficient residence time for the reaction to proceed.
- A simple channel typically suffices for homogenous reactions, whereas flow obstacles in the channel ("packaging") is useful to increase interfacial area in heterogeneous reactions.

So that microchannel based micro reactor, that is are actually procured where that reactions may be possible based on that interfacial area. So in that case, a mixture of the reactants that enters the reaction zone which provides the sufficient residence time for the reaction to produce and in this case the simple channel typically suffices for the homogeneous reactions whereas flow obstacles in the channel may be packaging, you can refer it, is useful to increase the interfacial area in heterogeneous reactions.

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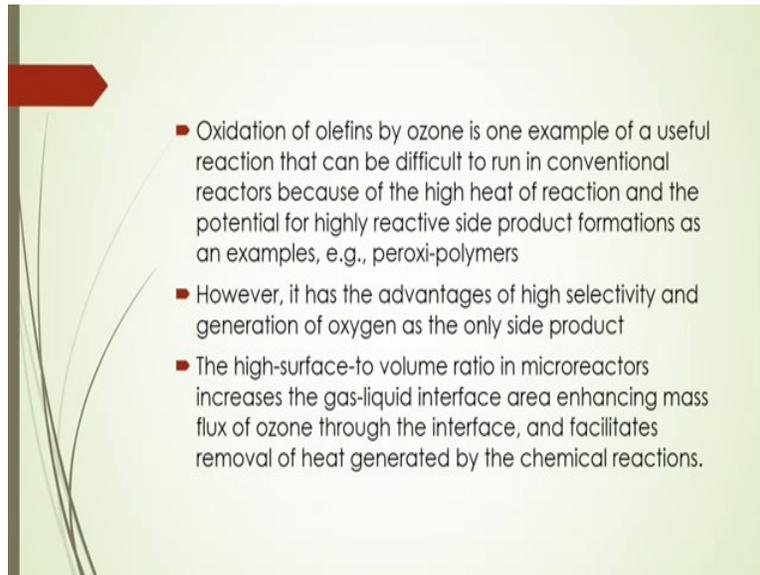


And in this case transport of the fluid elements within the microflow due to the deformation with elongation of the fluid elements which increases the length and decreases their width, that may yield you higher interfacial area. And in this case due to the small dimensions of the microchannels, this you know that Reynolds number values that is you know depends on velocity of the fluid, even geometry of the fluid and properties of the fluid are particularly low which may imply the laminar flow and in that case molar diffusive flux that will dominates the mass transport within the microchannels.

That is why, this molar diffusive flux is based on that Fick's law and is a function of the diffusion coefficient of a certain molecule and interfacial area. So this interfacial area will actually give you the you know that enhancement of the mass transfer based on this diffusive mass flux.

Now if you think about that oxidation of olefins by ozone, that may be the one of the example of useful reaction that can be difficult to run in a conventional reactors because of the high heat of reaction that is generated during that Ozonation process and the potential of high reactive side production that form based on these exothermic reactions like for peroxi-polymers there for an example, that is produced during this oxidation process. However in this case, it has the advantages of high selectivity and generation of oxygen as the only side-product there.

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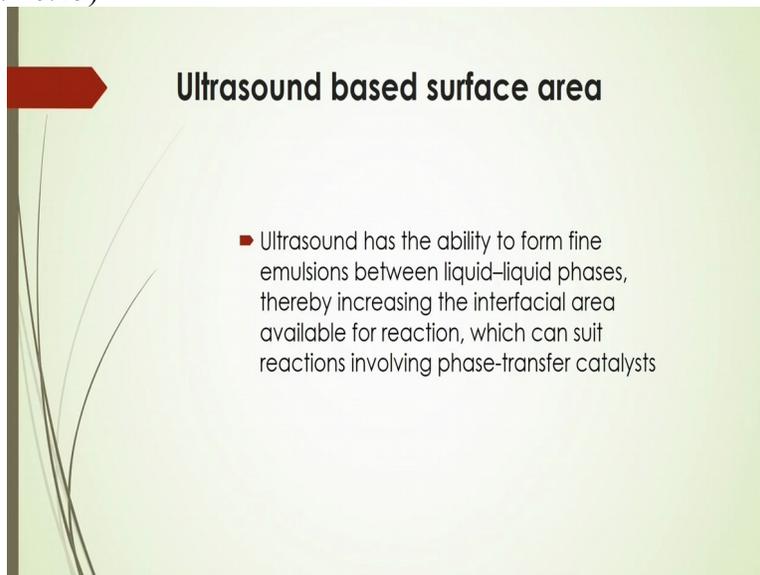


- Oxidation of olefins by ozone is one example of a useful reaction that can be difficult to run in conventional reactors because of the high heat of reaction and the potential for highly reactive side product formations as an examples, e.g., peroxy-polymers
- However, it has the advantages of high selectivity and generation of oxygen as the only side product
- The high-surface-to volume ratio in microreactors increases the gas-liquid interface area enhancing mass flux of ozone through the interface, and facilitates removal of heat generated by the chemical reactions.

So the high surface to the volume ratio in the microreactors you can have the increment of the gas liquid interfacial area that may enhance your mass transfer flux or mass flux you can say of the ozone through the interface. And it facilitates the removal of the heat generated by the chemical reactions. So the oxidation of the olefins by the Ozonation which is exothermic reactions that maybe you know that heat production should be higher and then reactive side production formations will be there along with that high temperature and now to reduce that temperature, you are just using that high surface area to the volume ratio in the microreactors to increase the gas liquid interfacial that may enhancing the mass flux of the ozone through the interface as well as it may be useful for the removal of heat by the chemical reactions through that interface.

So this is the advantage of that production of the interfacial through the microchannel.

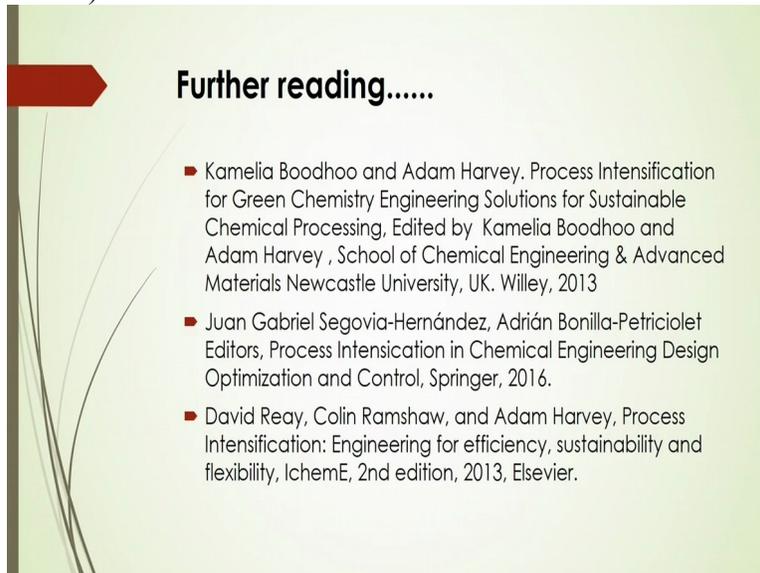
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Now another important mechanism, it is called ultrasound based surface area. This ultrasound, you know that has the ability to form the fine emulsions like liquid-liquid you know or gas-liquid or you know that gas-liquid-solid there is that slurry systems there. You can use that ultrasound to you know make that emulsions. That maybe liquid-liquid phases, so thereby increase in the interfacial area of the liquid-liquid you know interface like droplet, one liquid may be more lighter, liquid will be that discrete phases just forming that lighter liquid droplet and their interfacial will be there.

So that interfacial area may be available for the reactions which can suit reactions involving that face transfer catalysis.

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Further reading.....

- Kamelia Boodhoo and Adam Harvey. Process Intensification for Green Chemistry Engineering Solutions for Sustainable Chemical Processing, Edited by Kamelia Boodhoo and Adam Harvey, School of Chemical Engineering & Advanced Materials Newcastle University, UK. Wiley, 2013
- Juan Gabriel Segovia-Hernández, Adrián Bonilla-Petriciolet Editors, Process Intensification in Chemical Engineering Design Optimization and Control, Springer, 2016.
- David Reay, Colin Ramshaw, and Adam Harvey, Process Intensification: Engineering for efficiency, sustainability and flexibility, IChemE, 2nd edition, 2013, Elsevier.

So I think we have discussed a lot of things about that mechanism of formation of interfacial area and how that interfacial is related to the related to the mass transfer processes. So we will discuss more about that application of that interfacial area and also the specific that design of that reactors or that unit by which you can produce that interfacial area as well as you can increase the residence time and so that you can apply this mechanism of formation of interfacial area for the chemical engineering process intensification. So next lecture, we will discuss more about that interfacial area based chemical engineering process and unit design.

So I would suggest to read further about this interfacial area based chemical engineering processes from these references, even you can follow other reference also to get more information about the interfacial area based process intensification. So thank you for your attention here.