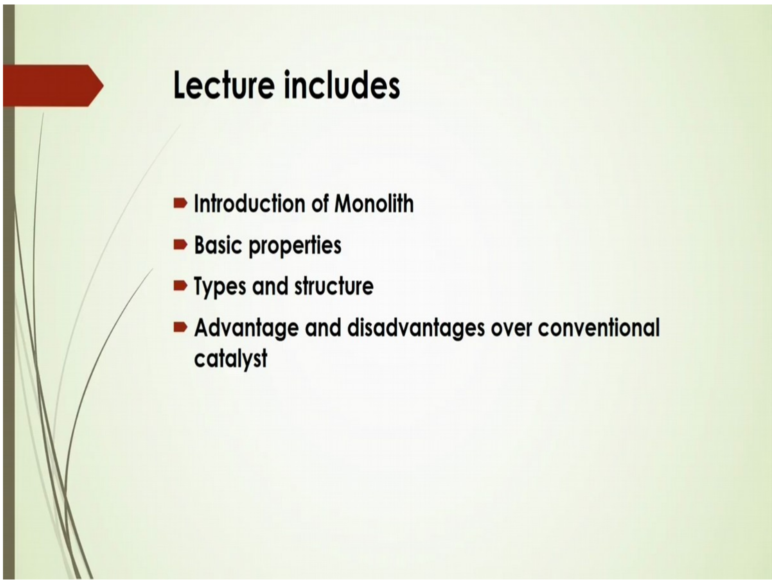
Chemical Process Intensification
Professor Dr. Subrata K. Majumder
Department of Chemical Engineering
Indian Institute of Technology Guwahati
Lecture 19
Introduction of Monolith Reactor

(Refer Slide Time: 0:29)

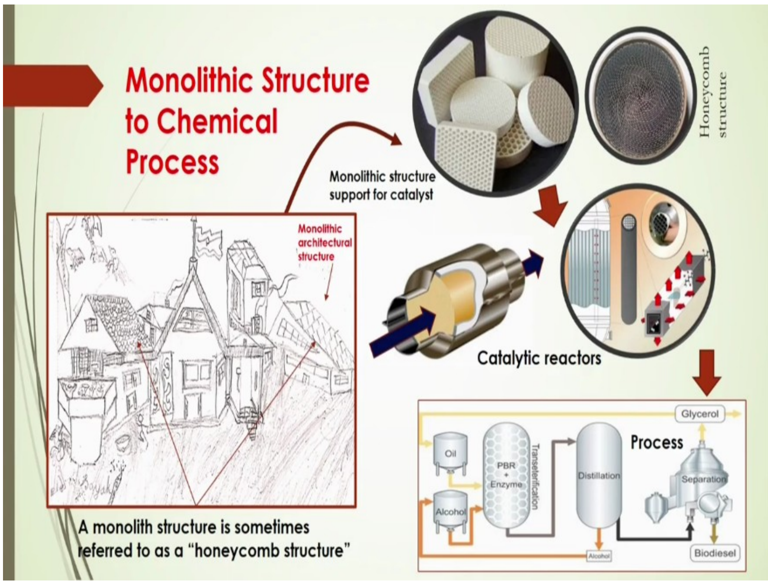
Welcome to massive open online course on Chemical process intensification. In this module, in module 7 we will discuss about process intensification by Monolith reactors.

(Refer Slide Time: 1:00)



And under this module in this lecture we will discuss something about monolithic reactors, its introduction, basic properties, types and structure and advantages and disadvantages of this monolith reactor over other conventional catalyst type reactor.

(Refer Slide Time: 1:16)



Now, as we know that there is a special structure which may increase the efficiency of the reactor based on the flow characteristics through the special structure. Now, based on that flow characteristics, the reactors are developed in a different way. This case the reactor based on the monolithic structure is one type where the chemical engineering process can be intensified based on the contact between the phases and also retention time and also other hydrodynamic aspects where we can get the benefit like you know that flow characteristics, flow pattern, even mixing characteristics, even ideal flow or non-ideal flow or it is called a flat flow other type of reactor based on this special structure of the reactor internals there.

Now, if you make the reactor internal in such a way that in the internal as a support you are using that internal for some catalyst, so that over the support that catalyst will be layered over the special structure of that internal and whenever flow through that catalyst then the reactor will act as a catalytic reactor for a special for a particular chemical engineering process where the catalyst particles will be in halt there.

Now that, what is that special structure and why it is called that monolithic one type of special structure based on which that monolithic reactors are now very important for the research scientist and they are giving more attention to this type of monolithic structure-based reactor where different chemical engineering process can be carried out.

Now, you will see that in ancient age where different architectural structures or concept that was actually use for the building of house, in the human life that they have actually designed their ancient age houses in different structure. So in that case one of the important structure it is called that monolithic structure, monolithic architecture structure. Here it is see in ancient age this house is made you know that roof is made of a particular structure, there it is called honeycomb structure, there is a special structure like this. This type of structure is called that honeycomb structure or it is a monolith structure, here like this here see how this stepwise this structure are made here. So this type of structure it is called monolith structure, so this is architectural structure, one architectural structure there.

So in ancient age they have used this type of structure there and in this case you will see that based on this architectural structure you will see that now researchers or scientists are thinking about that since the flow will be flowing through this structure, there we will have certain fashion of the flow and that fashionatic flow may be useful for certain chemical engineering process to get its intensification.

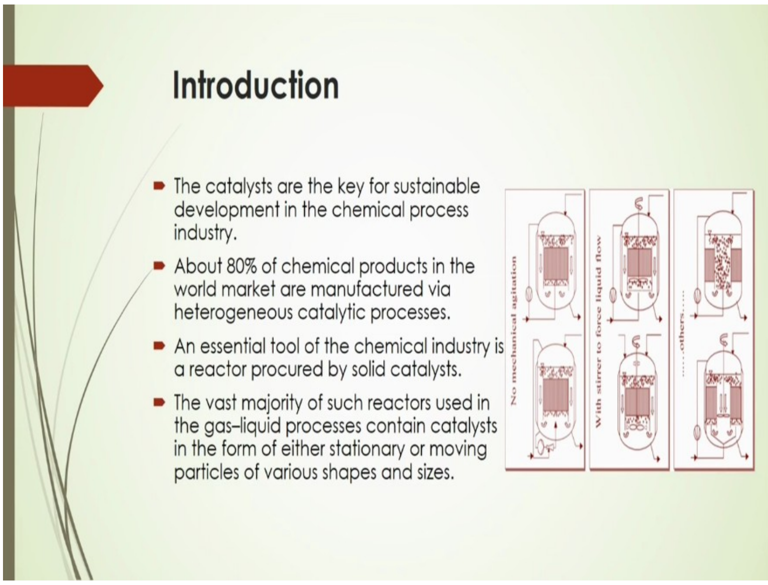
Now, this monolithic structure support for catalyst here, you see that this type of structures are there, this is called monolithic structure support for catalyst that means on this support the catalyst particles are layered in such a way that through which the reactants are flowing, during that flow there will be a reactions or chemical engineering reactions based on which you are getting different types of products by that intensification of the process.

Now, this is a different structure, so there are several structure also are there so this type of structure is called monolithic. Actually in last few decades different types of structures of catalyst are being used for particular chemical engineering processes, so monolith is one of the important structure also. I will show that what are the different structures of catalyst particles are used for the chemical engineering processes.

So based on this structure special structure of monolithic, this chemical engineering process reactors are being developed or designed to get the in intensification of that particle processes. Like here catalytic reactors, now these types of reactors are being used in what are vehicles just to remove the exhaust that is components from the exhaust their like carbon monoxide, NOx or COx, even SOx also to remove all those things in catlytic converters are being used there.

So here this type of, so there are several types of other reactors are also there, that reactors are being developed based on this special structure and that structure since are used actually for that chemical engineering process. One of the examples like that transistor application to actually produce the biodiesel, so they are also this monolithic structures, catalyst are being used for getting up process intensification.

(Refer Slide Time: 7:57)



So, in this case we are seeing that here the catalyst are the key for the sustainable development in the chemical process industry, so that is why whenever you are going to use that catalyst for a certain chemical engineering process intensification for sustainable development, then we are thinking about that how this catalyst can be used there. And about 80 percent of that chemical products in the world market are manufactured via heterogeneous catalytic processes.

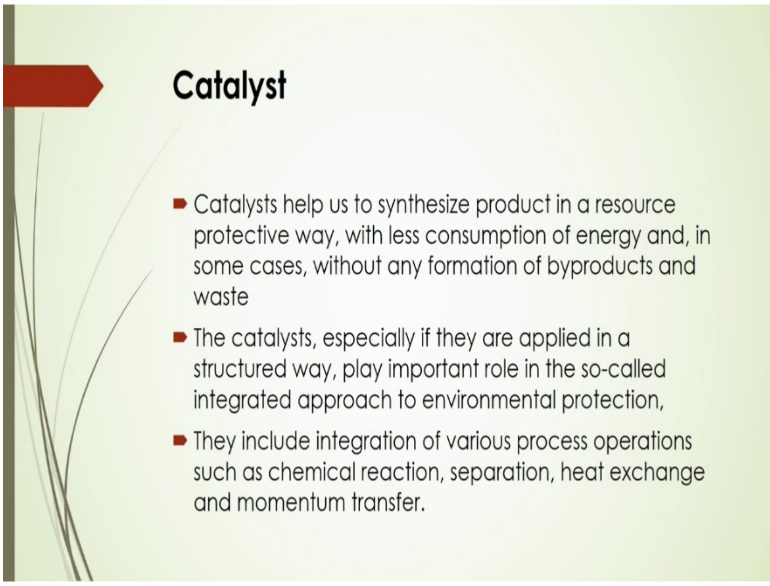
So in that case these catalysts are very important and how that catalyst particles can be used in a particular structure so that we are getting that intensification of the process. Also an essential tool of the chemical industry is the reactor that is procured by solid catalyst, in that case the reactors will be produced based on that solid catalyst layout.

And the vast majority of such reactors used in get-liquid processes and that contains catalyst in the form of either stationary or moving particles of various shapes and sizes. So you are actually or nowadays that reactors are being developed based on that catalyst how it should be oriented in the reactor whether it should be stationary or moving particles of various shapes or sizes, so in that direction it is being developed and there is monolithic structure on which that catalyst particles are being supported so that based on that catalyst support material as a structure of monolithic structure the reactors are being developed for the different chemical engineering processes specially multiphase processes are very important here.

In this figure it is shown that some reactors are there, in this case simple stirred tank reactors are being replaced by just adding inside the reactor there will be monolithic structure. And that monolithic structure you know that through which flow will be flowing, where we can get that certain fashion of the flow or pattern of the flow and based on which we are getting that intensification.

We will be discussing later on in details more about these type of reactors, how different flow patterns are actually formed and what are the different hydrodynamics and also based on that hydrodynamics how the chemical engineering reaction is being carried out and how should be intensified compared to the conventional reactors.

(Refer Slide Time: 11:02)

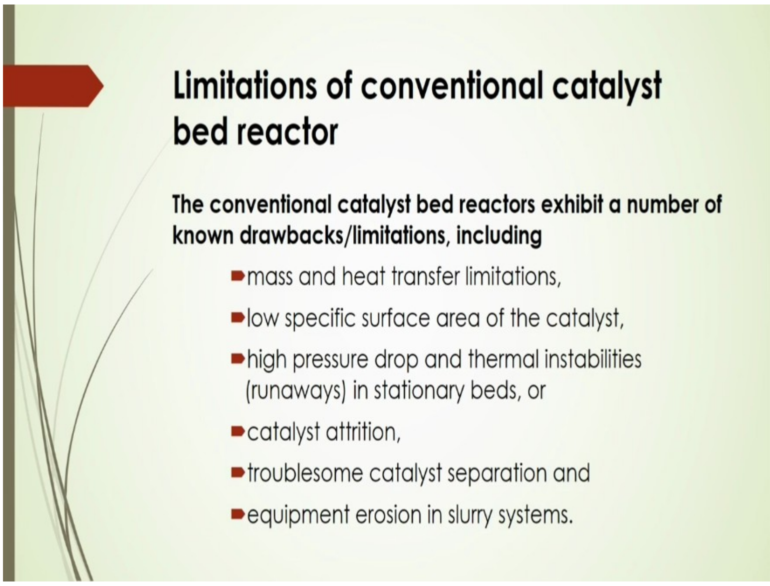


Now, before going to the details of monolithic catalytic reactors, you have to know something about catalyst. What is the catalyst? Catalyst helps us to synthesise product in a resource protective way with less consumption of energy and in some cases without any formation of by products and waste, so you have to synthesise or develop some catalyst where you can get that reaction output with less consumption of energy and the formation of by products that will be more useful and also that should not be hazardous there.

And the catalyst especially if they are applied in a structured way, play that important role in the so-called integrated approach to environmental protection. And also this type of catalyst also include integration of various process operations such as chemical reactions, separation, heat exchange and momentum transfer also. So any chemical engineering process these things are very important that chemical reactions, separation, heat exchange and also momentum transfer so you are going to intensify the chemical engineering process based on this chemical reaction, separation, heat exchange and momentum transfer are there.

So in that case for the chemical engineering reaction if you are going to use that catalyst, how to use that catalyst in such a way that whether it should be made a special structure or you are going to use it conventional way or not. So since this monolithic structures are giving the intensification of the process so that is why the monolithic reactor based on that catalyst on which it is being supported, the reactors are being developed for chemical engineering processes.

(Refer Slide Time: 13:30)



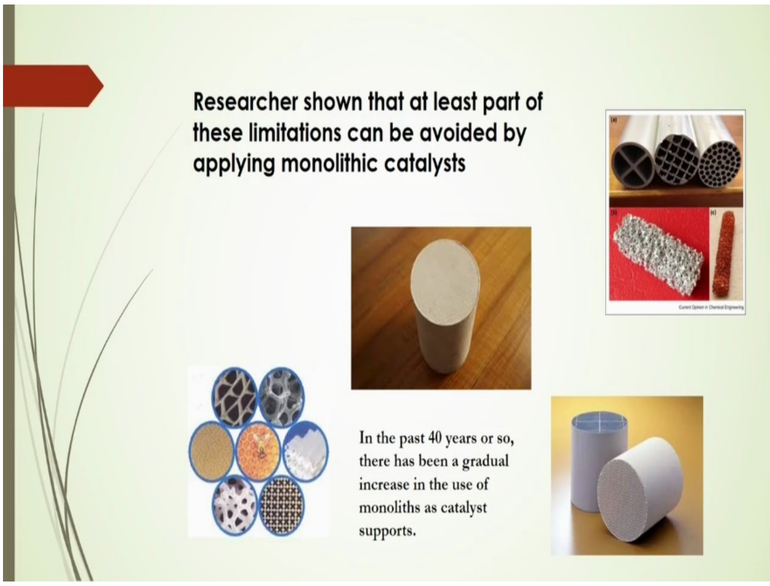
Now, what are the limitations of that conventional catalyst bed reactor? In that case you will see that we are getting still now that there are several existing conventional catalytic bed reactors, where exhibits number of drawbacks and limitations there, those includes like mass and heat transfer limitations are there, low specifics surface area of the catalyst, even high pressure drop or thermal instabilities like pack bed, tickle bed even you know that other different types of packing material, even fluidized bed also the catalytic fluidized beds also there.

In that case sometimes that catalyst iteration is being happened and also you know that melt distribution of catalyst sometimes this will happen and we are not getting that 100 percent utilisation of the catalyst surface there. So this types of shortcomings are there, even sometimes it is very difficult to overcome the troubles from catalytic separation there. And also equipment evolution in slurry systems are there.

So this types of drawbacks or limitations are there in the existing conventional catalytic reactors are there, so that is why the development of existing catalytic reactors to get the process intensification, it is now you know being developed and it is going towards that one type of reactor like monolithic reactors, monolithic catalytic reactors there.

Even we have discussed several different other types of chemical engineering process intensification not only on the catalyst bed, there are several others we also do get the process intensification. So here catalyst bed reactor is one type of where that monolithic structure can be involved, so this type of reactors will be more useful to get the process intensification.

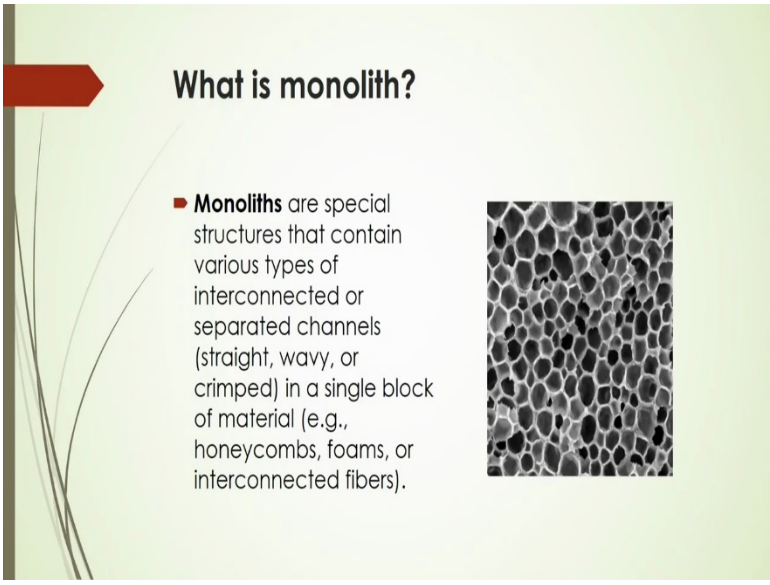
(Refer Slide Time: 14:50)



Now here, researchers have shown that at least part of these limitations whatever we have discussed that can be avoided by applying monolithic catalyst there. So there are several different types of monolithic structures are there, in the first 40 years or so there has been a gradual increase in the use of monoliths as catalyst supports are there.

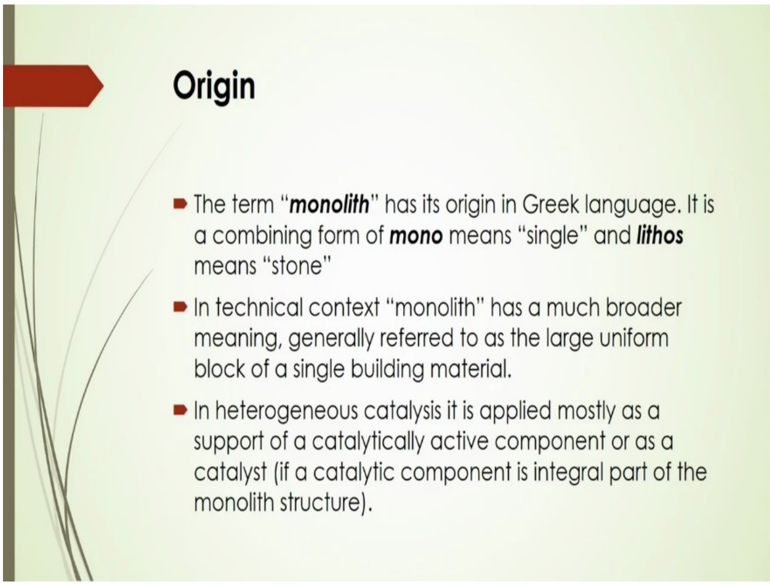
So there are here sometimes honeycomb structures and sometimes you know that comb structure and you know sometimes it will be rod structure in which there will be monolithic structure will be inside that rod and these are the honeycomb structures are there. So this type of structure is being actually developed to get more surface area, less pressure drop, even wall mixing, flat flow phenomena so that we can get the process intensification for that particular chemical engineering process.

(Refer Slide Time: 15:47)



Now question is that, what is that monolith, how it can be actually defined there? So the monoliths are special structures you can say that it contains various types of interconnected or separated channels may be you know that it will be straight channel, wavy channel or crimped channel also in a single block of material there. Examples like honeycombs, foams or interconnected fibres, so these are the different structures of monolith, so that is why monolithic is a special structure that contains various types of interconnected or you can say separated channels, that channels may be you know that may be straight or wavy or other types also.

(Refer Slide Time: 16:33)



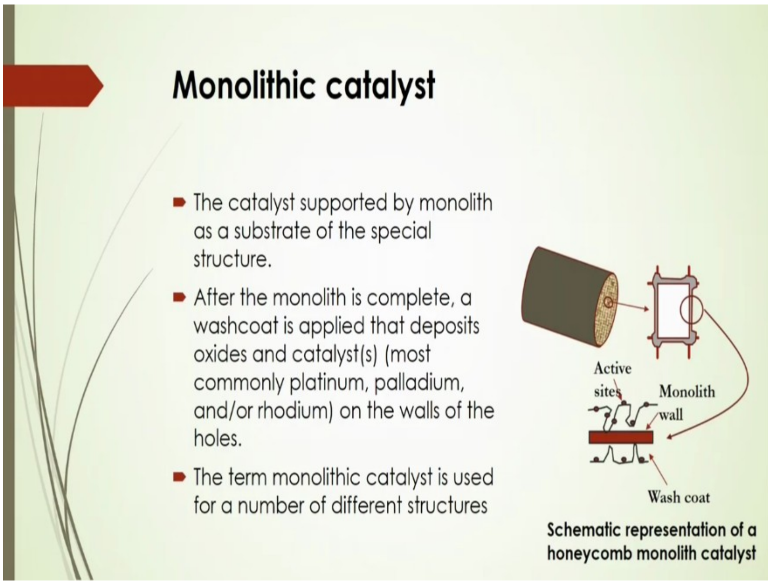
Now, where that actually this monolith term has come? The term “Monolith” has its own origin in Greek language, it is a combining form of Mono means “single” and lithos means here “stone”. So Mono means that a single and lithos means stone, so monoliths means simple single stone there. So in technical context this monolith has much broader meaning like you know that generally it may be referred to as large uniform block of a single building material you can say.

And in that case this type of structure may be used in heterogeneous catalytic reactor where this hydrogen is catalyst will be applied mostly as a support of a catalytically active component or as a catalyst if a catalytic component is an integral part of the monolith structure there. And you know that how actually this monolith construction can be done or what are the materials actually being used for this monolith structure construction there.

(Refer Slide Time: 17:49)

So as per basic construction material there are mostly too types of materials based monoliths you can get. Generally they are procured based on that you know that ceramic material and also metallic structure there. So in the ceramic cases, mainly cordierite type materials will be used, in that case actually this type of materials will be like silicate mineral that is found in metamorphic and igneous rocks, and also metallic there it will be mainly stainless steel, metal alloys, et cetera. So we can say that there are two types of materials are being used for construction of monolithic structure there; one is ceramic and other is metallic structure.

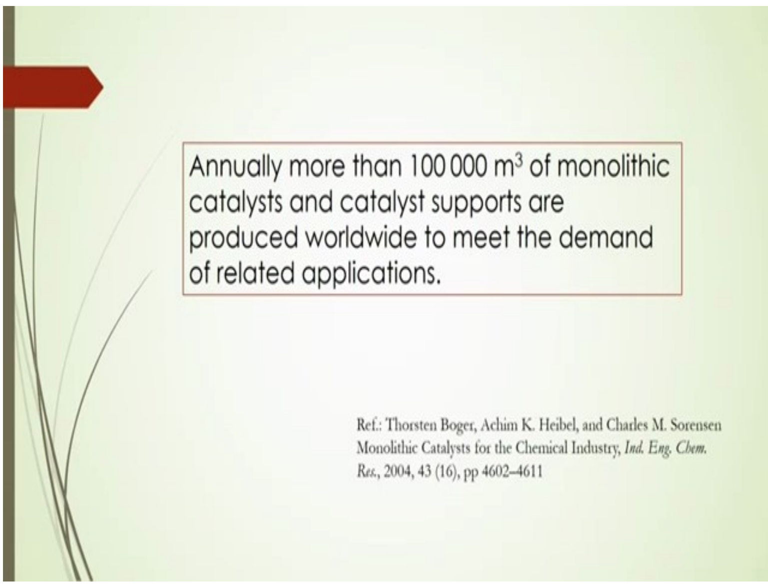
(Refer Slide Time: 18:46)



Now, the catalyst that is supported by monolith as a substrate of the special structure there. And after the monolith is complete, wash coat is to be applied there as per the picture shown here that deposit oxide and catalyst, and in that case mostly you know that platinum, palladium or rhodium on the walls of the holes there.

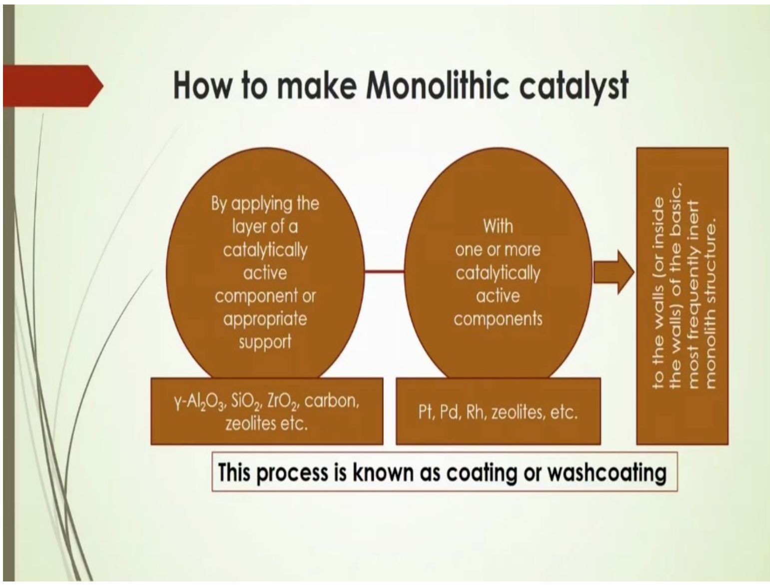
So one support that is to be required that is a wash coat to be applied to deposit oxide and catalyst there. And the term monolithic catalyst is used for a number of different structures there, in that case you will see this may be channel based structure may be you know that other different types of structures there will be there. So these monolithic structure are different way to be made there.

(Refer Slide Time: 19:44)



And annually more than 1 lakh meter cube of monolithic catalyst and catalyst supports are produced worldwide to meet the demand of related applications as per Thomson Boger that is reported in 2004 there.

(Refer Slide Time: 20:19)

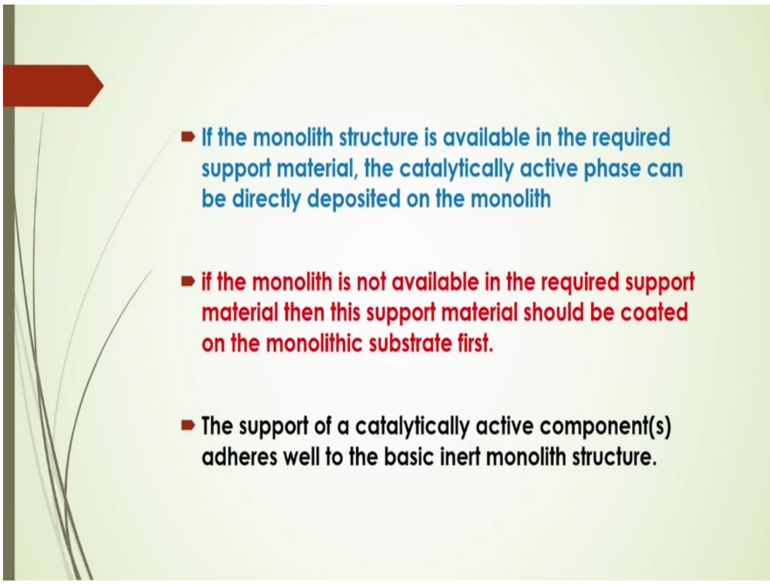


And how to make monolithic catalyst? You will see by applying the layer of catalytically active component or appropriate support, and then of course it will be made to walls or inside the walls of the basic most frequently inert monolithic structure there. But whenever you are procuring their monolithic catalyst by applying layer of a catalytically active components or appropriate support, you have to make it with one or more catalytically active components there.

Now catalytically active components like you know that Gamma aluminium oxide, silicon dioxide, zirconium oxide, carbon zeolite, etc., even one more catalytically active components are there, they are platinum, palladium, rhodium, even zeolite, etc. are being used catalytically active components where the supporting materials will be oxides like aluminium oxide, silicon dioxide, zirconium dioxide, like this.

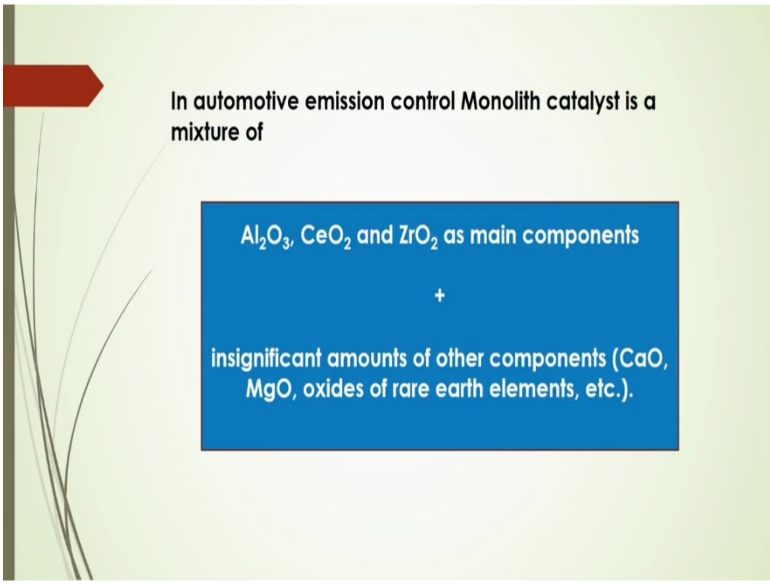
So this process is known as sometimes it is called Coating or wash coating. And in this case this you know that will be done to the walls so that the walls that catalytic layers will be produced and then you can use as a catalytic reactor or for that chemical engineering process.

(Refer Slide Time: 21:42)



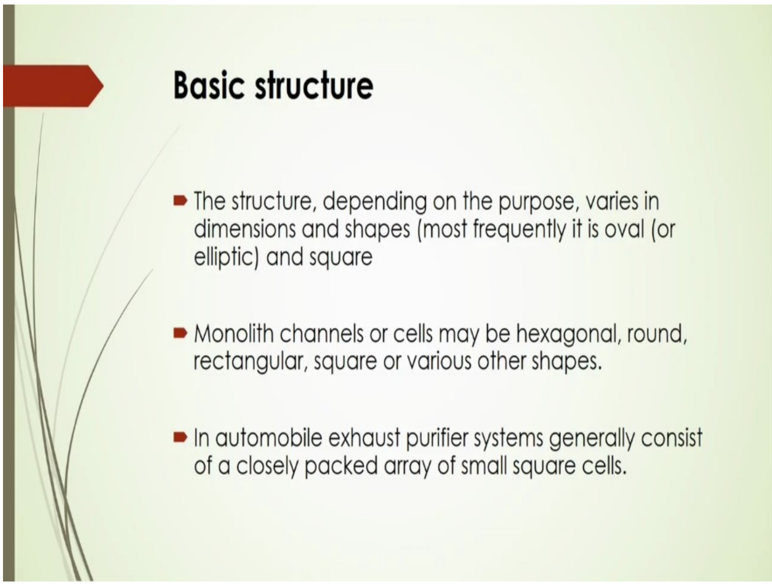
If the monolithic structure is available in the required support material, the catalytically active phase can be directly deposited on the monolith. And if the monolith is not available in the required support material then of course this support material should be coated on the monolithic substrate first. And support of a catalytically active components adheres well to the basic inert monolithic structure there.

(Refer Slide Time: 22:10)



And mostly use this type of catalytic reactors or catalytic converter in automobile where the control of emission in the monolithic catalytic converter. In that case that monolithic catalyst will be mixture of aluminium oxide, cerium oxide and zirconium oxide as a main components, and also insignificant amounts of other components like calcium oxide, magnesium oxide, even oxide of other rare earth elements, et cetera. So this type of materials are generally being used for automobiles to control the emission by monolithic catalytic structure.

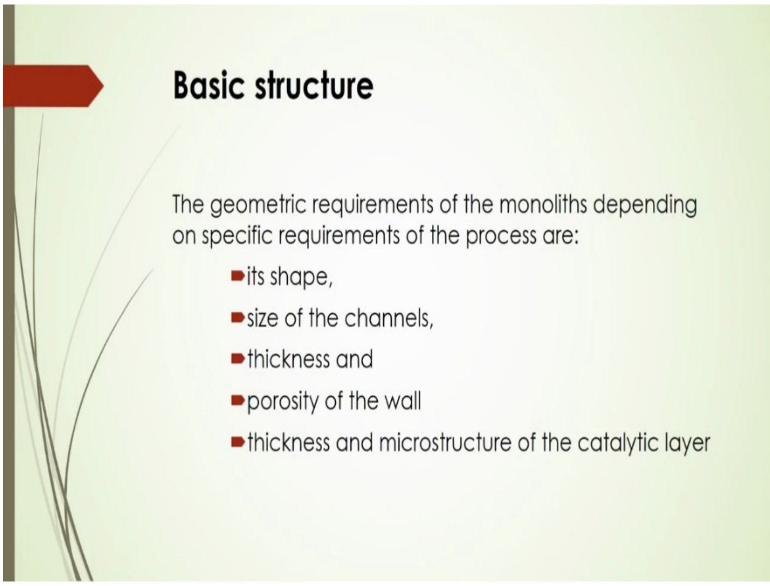
(Refer Slide Time: 22:53)



And what are the basic structure for that? The structure that depends on the purpose varies in the dimensions and shapes, most frequently it is oval or elliptical and also square you can say. And monolith channels or cells may be you know that hexagonal, round, rectangular, square or various other shapes there. In automobile exhaust purifier systems generally consists of a closely packed array of small square cells there.

So in the catalytic converter there in the automobile you will see that the monolithic structure will be small square cells there where it will be packed as an array there. So this type of structure is being used to just getting the catalytic reactions and to remove that exhaust gases like carbon monoxide, carbon dioxide, sulphur dioxide, all those things, so that is why catalytic converter based on this monolithic structure in the automobile industry are nowadays very important where it is being used for that process intensification.

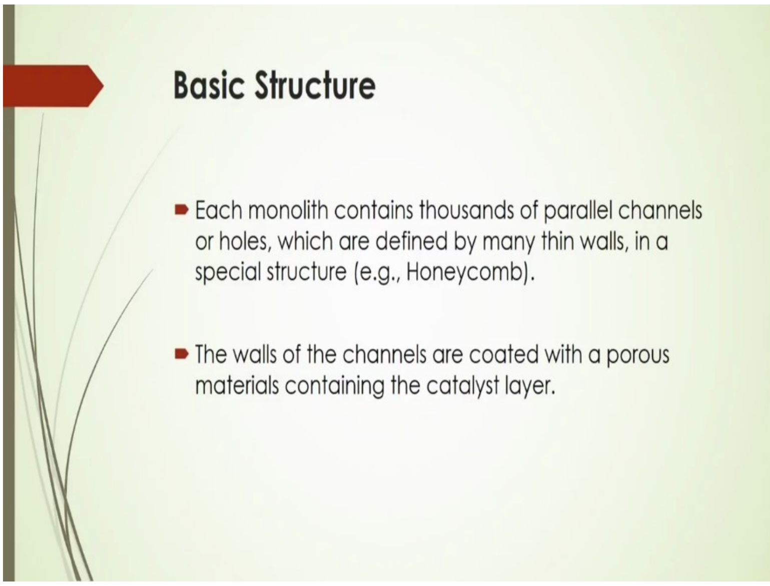
(Refer Slide Time: 24:11)



And the geometric requirements of the monoliths that depends on some specific requirements of the process like it is shape, size of the channel, even what should be the thickness and also what should be the porosity of the wall that is also important and whether you are going to make it a micro structure layer or not, so the thickness of the microstructure in a catalytic is also important there.

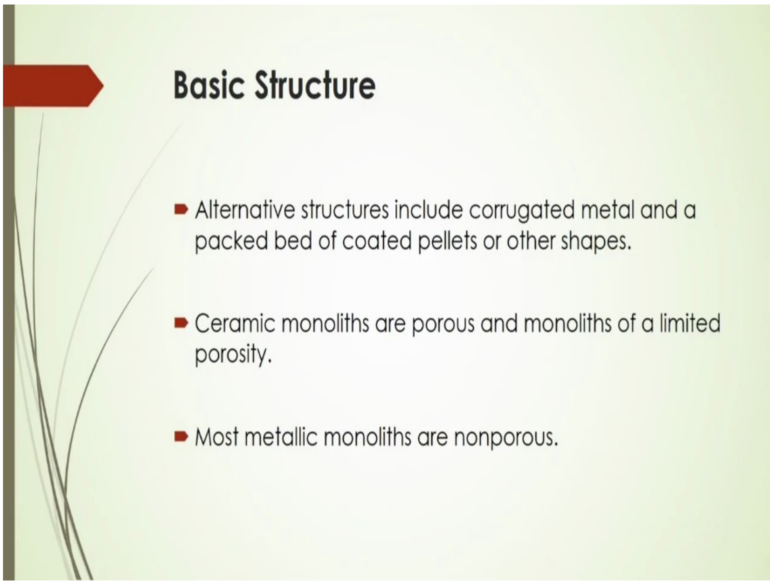
So you have to consider whenever you are going to make a particular structure, what should be the shape, what should be the size of the channel. If it is channel based monolithic structure you are making and what should be the thickness, porosity of the wall and thickness, so all those things actually effect on reaction performance or reactor performance there, reaction yield there and conversion also there. So you have to optimally design the reactor based on that monolithic structure based on the different shape and size.

(Refer Slide Time: 25:17)



And each monolith actually contains thousands of parallel channels or holes which are defined by many thin walls in a special structure example, honeycomb there. And the walls of the channels are coated with a porous material that contains the catalytic or catalyst layer there.

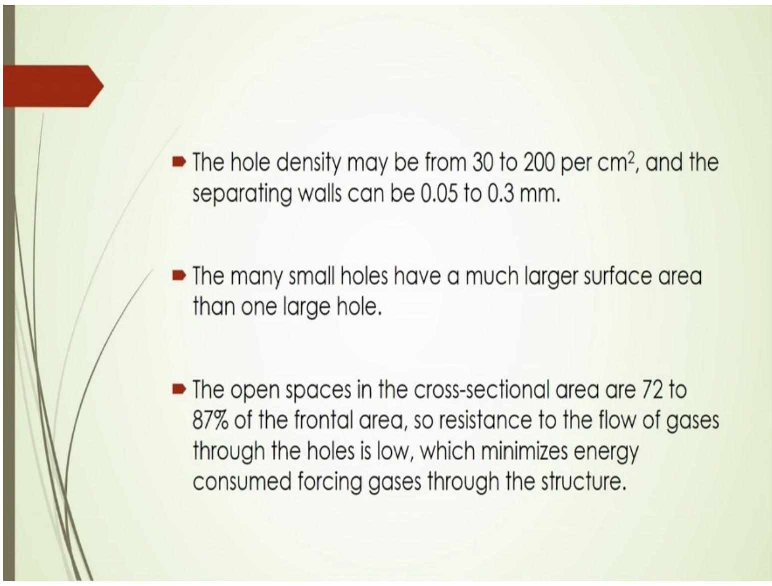
(Refer Slide Time: 25:43)



And also alternatively you can have different structure also that may include corrugated metal and packed bed or coated pellets or other shapes there. Ceramic monoliths are also porous and monoliths of limited porosity, most metallic monoliths are nonporous are there so that is why in that case you have to think about whether this metallic or foam based or ceramic based there or not.

So ceramic monoliths are generally porous and monoliths of a limited porosity will be there, whereas metallic monoliths are nonporous there. So porous materials may be more useful than metallic one, but sometimes ceramic materials may not be used for certain reactor may be their mechanical strength, but where metallic monoliths are more useful because of that thermal strengths there for particular reactor and for the specific application there, where temperature is very high there.

(Refer Slide Time: 27:25)

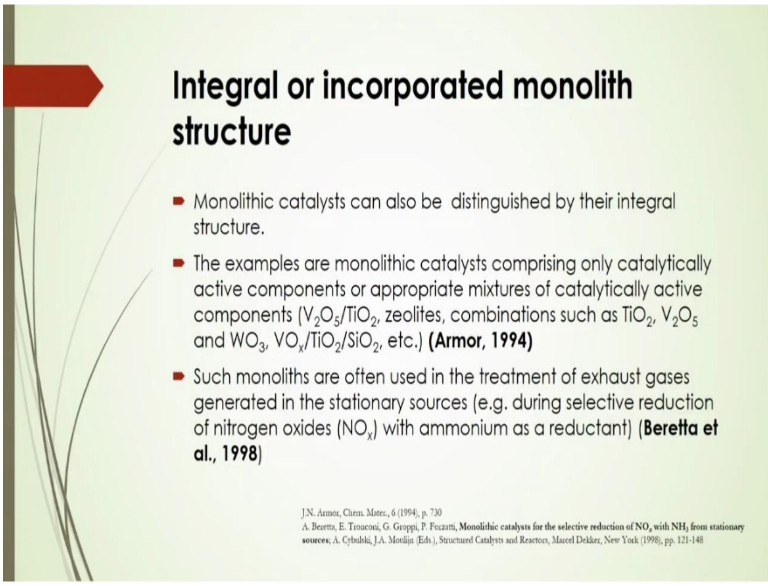


The whole density may be from 30 to 200 per centimetre square and the separating walls can be you know that sometimes 0.05 to 0.3 millimetre there. Many small holes have a much larger surface area then large hole, so in that case more reaction performance will be there because that surface area matters there, so more interfacial area will get between the phases and then you can get the better performance of the reaction in that direction the intensification of the process will be there.

And also the open space in the cross-sectional area that will be 72 to 87 percent of the frontal area should be there, so resistance to the flow of gases through the wholes will be low, which minimises the energy consumed that forces gases through the structure. So you have to have the open space in a certain optimised condition generally 72 to 87 percent of the frontal area otherwise, you will see that there may be more resistance there, so to get that optimal flow by less resistance of the flow of gases through the holes in that case you have to design that reactor to use that minimum energy consumption to force that gases through the structure also.

So that is why the shape and size and the channel size, channel length and also some other thickness of that channel catalytic layer inside the channels what should be that that is very important there. If you are getting small holes there, so there may be pressure drop will be higher, but maybe you have to then think about what type of liquids are being used and also how that channels are made, so based on that there will be optimisation based on the different variables of operating conditions based on which you can design that monolithic structure and getting the process intensification.

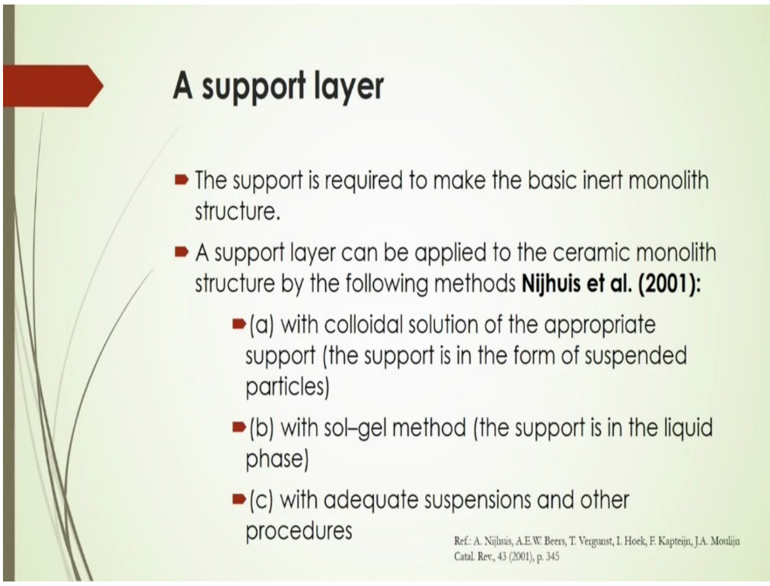
(Refer Slide Time: 29:10)



Also integral or incorporated monolith structure, how to incorporate the different structures or different catalyst particles on that monolithic structure is there. So monolithic catalyst can also be distinguished by their integral structure also. The examples are monolithic catalyst that comprises only catalytically active components or appropriate mixtures of catalytically active components like Vanadium Pentoxide or Titanium dioxide, zeolites, combinations such as silicon dioxide, Vanadium pentoxide and other oxides also there.

So as per Armor (1994) they have given this monolithic catalyst structure that comprises based on these materials of Vanadium pentoxide, Titanium dioxide and Zeolite and also combination of different oxides like this. And such monolithic are often used in the treatment of exhaust gases that is generated in the stationary sources like during selective reduction of nitrogen oxides with ammonium as a reductant as per Beretta et al. (1998).

(Refer Slide Time: 31:29)



Now to get that monolithic catalyst structure you have to have some support layer of that catalyst in that particular structure, so the support is required to make the basic inert monolith structure, in that case the support layer can be applied to the ceramic monolith structure by the following methods that is given by Nijhuis et al. (2001). So as per their observation that support layer can be applied to the ceramic monolith structure with the colloidal solution of the appropriate support, the support is in the form of suspended particles. Even you know that sol-gel method the support is in the liquid phase also there.

And with adequate suspension and other procedures also can be applied to get support layer which can be applied to the ceramic monolithic structure by the following methods there. So that is why the support is required to make the basic inert monolith structure and you have to follow to make this structure in a particular way.

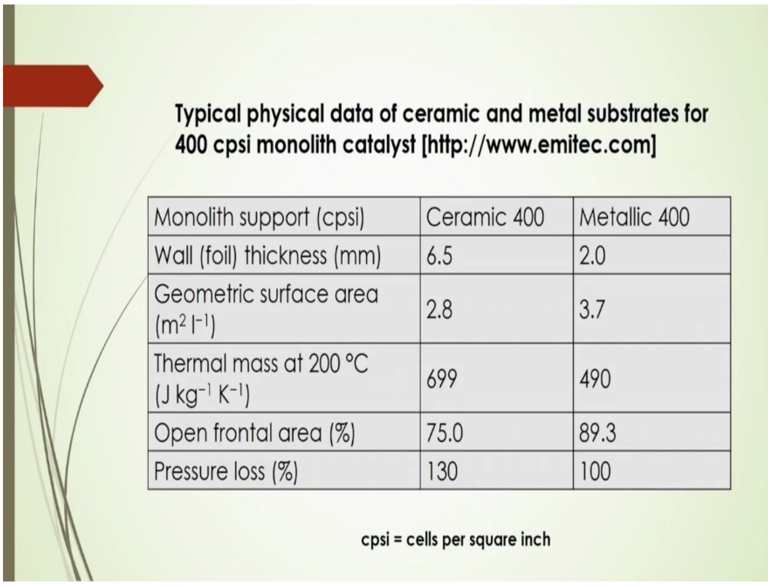
(Refer Slide Time: 31:52)

The prepared support is coated with a catalytically active component by conventional methods for catalyst preparation like impregnation, ion exchange, co-precipitation, et cetera, these are the method by which you can coat the prepared support with catalytically active components by conventional methods. A catalytically active component and support material can be coated on the basic monolithic structure, simultaneously as so as to achieve like required porosity, good mechanical properties, high dispersion of catalytically active components there.

And the catalyst like zeolites that may not actually need a specific support material and that can be coated or synthesized directly on the monolithic structure monolithic support there. So that is why all catalyst may not require that specific support material, but maximum cases it is required that a support is required for getting a layer of catalyst over there.

So in that case whenever you are making that support by that catalytically active components, in that case you have to procure that support in such a way that took to achieve the required porosity, even mechanical properties that should be very acceptable or suitable range, high dispersion of catalytically active component should be there. So this is the case where you have to remember these points of porosity formation, mechanical properties how it is varying and also dispersion of catalytically active components will be there over the support how it will there, all these things to be actually remembered during the design of the monolithic structure.

(Refer Slide Time: 34:41)


Typical physical data of ceramic and metal substrates for 400 cpsi monolith catalyst [http://www.emitec.com]

Monolith support (cpsi)	Ceramic 400	Metallic 400
Wall (foil) thickness (mm)	6.5	2.0
Geometric surface area ($m^2\ l^{-1}$)	2.8	3.7
Thermal mass at 200 °C ($J\ kg^{-1}\ K^{-1}$)	699	490
Open frontal area (%)	75.0	89.3
Pressure loss (%)	130	100

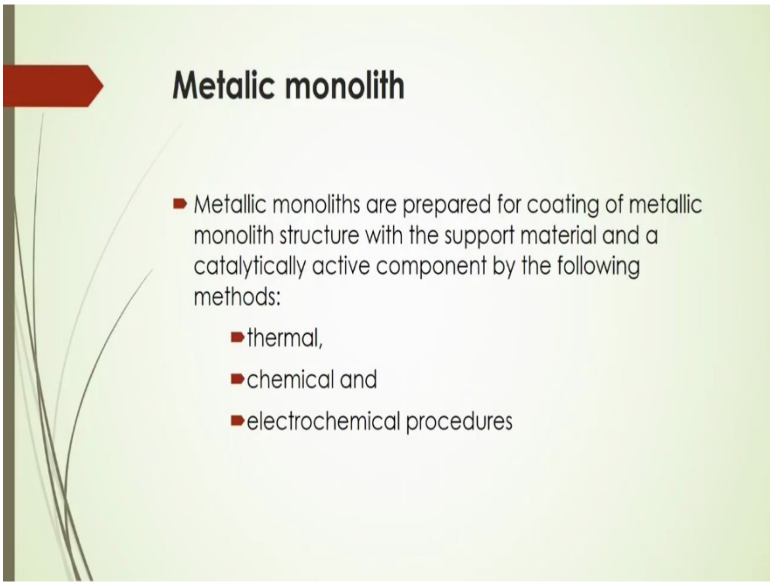
cpsi = cells per square inch

Typical physical data of ceramic and metal substrates for 40 cpsi monolith catalyst is given that is as per the website I have collected and it is as per the information that is given in the website, where they have actually reported that monolith supports that is structure will be in terms of cells per square inch that is called cpsi. And that case you know that what should be the wall thickness and geometric surface area what should be that, thermal mass, even open frontal area, how the pressure loss will be there.

If you are considering that ceramic materials 400 specific that structure, in that case the specific material of ceramic 400, in that case the wall thickness should be maintained at 6.5 millimetres as wall foil, and in that case you will see geometric surface area you may get as 2.8 meter square per litre. And also the thermal mass at 200 degree centigrade it should be 699 joules per kg per K, and open frontal area for this ceramic material it would be 75 percent, and pressure loss there it is found to be 130 percent there.

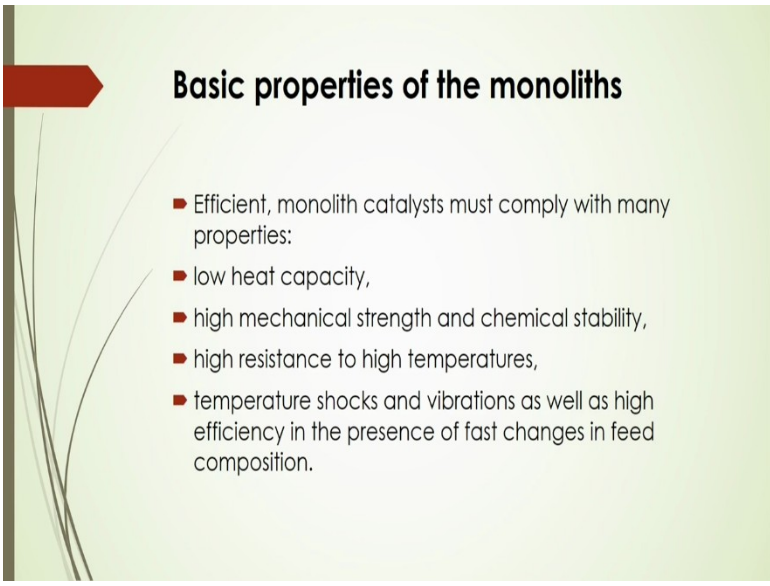
Whereas, in case of metallic structure there the wall thickness should be 2 millimetre, and geometric surface area should be 3.7 meter square per litre and thermal mass 200 degrees centigrade should be joules per kg per K that will be 490 joules per kg per K. Even the open frontal area should be 89.3 percent and there it is seen that the pressure loss it is 100 percent will be there. So these are the comparison of typical physical data of ceramic and metallic substrates for 400 cpsi monolith catalyst structure there.

(Refer Slide Time: 36:49)



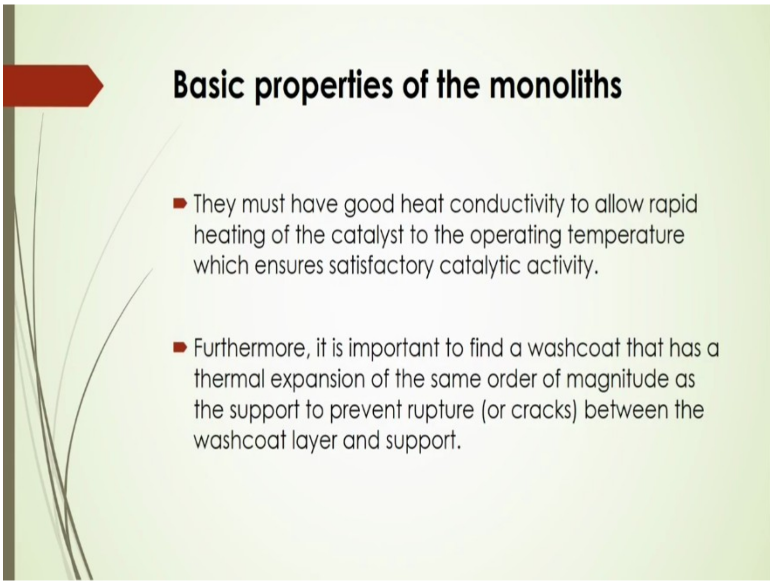
And metallic monolith are prepared for coating of metallic monolith structures with support material and catalytically active components by the following methods like thermal, chemical and electrochemical procedures are there.

(Refer Slide Time: 36:54)



Now, what are the basic properties of monoliths? So you have to know some properties of monoliths, in that case whether it should be efficient monolith catalyst or not, so in that case efficient monolith catalyst must comply with many properties, in that case low heat capacity should be there, high mechanical strength and chemical stability will be there, and high resistance to high temperatures. Even temperature shocks and vibrations as well as high-efficiency in the presence of fast changes in the feed composition should be there, so these are the basic structures of the monoliths that should be known before going to design that monolithic structure.

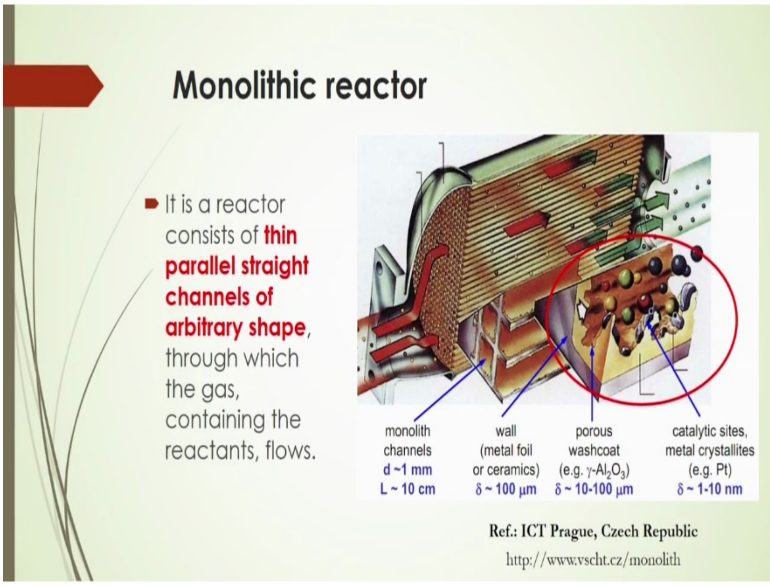
(Refer Slide Time: 37:41)



And also these monoliths must have good heat conductivity to allow rapid heating of catalyst to the operating temperature which ensures satisfactory catalytic activity. Also, you have to remember that it may be what to find a wash coat that has a thermal expansion of the same order of magnitude as the support to prevent some ruptures or cracks between the wash coat layer and support there. So that is why you have to consider that what should be the tolerance of the temperature of that material that you are considering for designing that monolithic structure there.

It is very important because any chemical engineering reaction you will see there may be temperature bond. Sometimes you know that it may be at higher temperatures, it may be exothermic reaction so during which there may be formation of high-temperature, even sometimes pressure will be high so in that case that monolithic structure should be made based on these properties of these monoliths there, so that you have to consider all those things that before going to design of that monolithic structure.

(Refer Slide Time: 39:08)



Now, what is that monolithic reactors, you will see the typical reactors are there as per ICT Prague Czech Republic, they are actually procuring these types of reactors, this is called honeycomb-based channel based monolithic reactor. And in this case the reactor as shown in figure here, you will see that this reactor consists of thin parallel straight channels of arbitrary shape through which the gas containing the reactance that will flows through that channel gap.

So in this case so it is simply a channel based that will be parallel straight channels, that channels may be you know arbitrary shape, wall shape, square shape, rectangular shape, different types of shapes will be there. So in this case monolith channels are there, you will see that identity is given there, here monolith channels should be around here diameter will be 1 millimetre, length is 10 centimetre as shown there in the figure in this case.

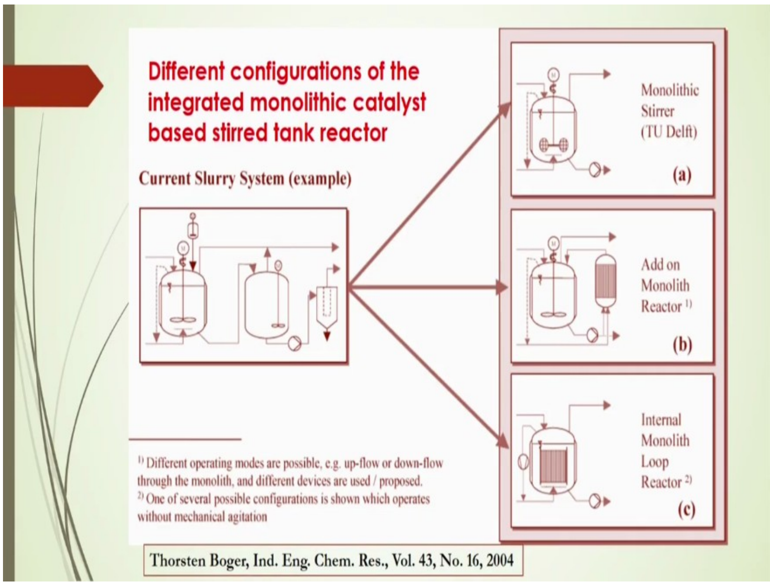
And whereas, wall that is metal foil that is called support, in that case it should be metal foil or ceramic type there. And in this case the thickness should be very small, it is around 100 micrometres whereas, that porous wash coat actually should be one which that catalyst particles will be there, so in that case it should be of material of Gamma, aluminium oxide so the thickness or diameter of that porous wash coat it should be is equal to 10 to 100 micrometres in thickness.

And also catalyst sites metal crystallites, et cetera of like that platinum-based catalytic sites like platinum catalyst is there, so over that you know that there will be catalytic materials there and there this layer thickness should be 1 to 10 nanometre range.

So in this case you are getting that how the support that is channel based support is there and the support there will be wall and then porous wash coat over which that catalyst particles will be placed and then making a layer of that catalytic site and through which that gas that containing the reactants will flow and then will be reactions occur in presence of this catalyst layer. So in this way these monolithic reactors can be developed.

So in this case the walls of the channels are coated with a porous ceramic containing that catalyst layer. And also the transition from reactants to products that will involve transport of the reactants by convective flow in the channels and also molecular diffusion toward the channel walls. And we will see that simultaneous diffusion and reactions occur inside the porous wash coat whereby the product diffuse back into the gas and are transported out from the reactor, so this is the monolithic reactors, how it is actually functioning that are given to you.

(Refer Slide Time: 42:36)

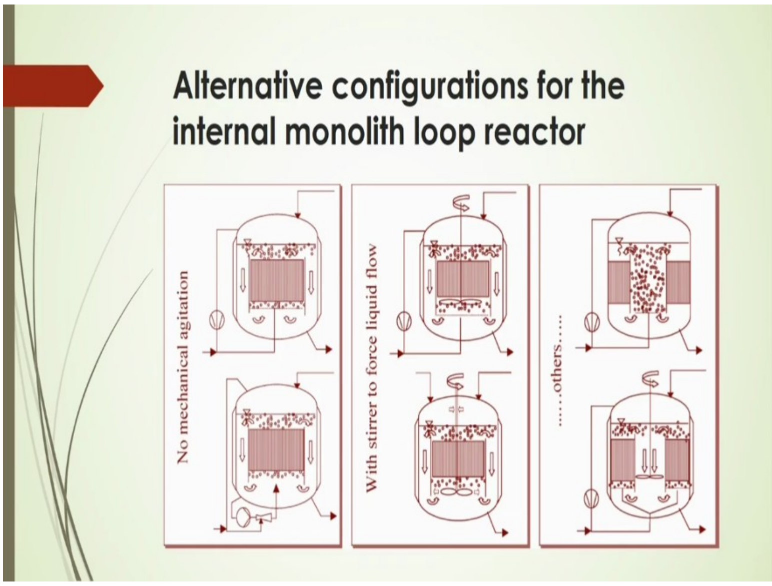


Now different other configurations you may have for monolithic structure where maybe useful for particular chemical engineering processes like integrated monolithic catalyst based on stirred tank reactor also there. So in that case we know that the current slurry system, how the catalytic slurry reactors are being working there in the chemical engineering process; gas, liquid, solid reactions are there, where this thing is actually being intensified by utilising that monolithic structure incorporating that monolithic structure, getting integrated with that monolithic structure in the stirred tank reactor. That integration may be into that the monolithic stirrer may be that in the monolithic structure also.

Even you know that Add-on monolithic reactor like it may be externally low where you know that there will be reactions occurred outside that reactors through that monolithic structure and then it is again you know passing through that stirrer. And then internal monolithic loop reactor also there, this may be externally loop, this may be internally loop there.

So that is why you are getting different structures of this monolithic structure for the reaction in a gas, liquid, solid system where conventional slurry system may be replaced by this monolithic reactor there.

(Refer Slide Time: 44:20)



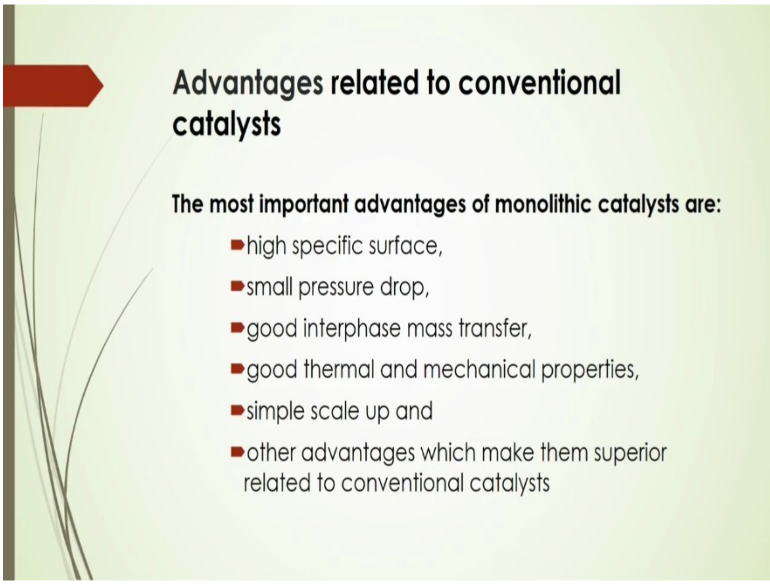
And also, you are getting alternative configurations for the internal monolithic loop reactors like sometimes where you will see that sometimes that mechanical agitation may not be required for that particular process, so through the monolithic structure there will be a flow of fluid, it may be laminar way that laminar flow condition and it may be the flat flow phenomena will be there through which that reactions will be actually occurred.

So this type of configurations as shown in the slides, you can get other different types of configurations. Nowadays, various investigators, researchers, they are actually developing different type of monolithic reactors, how that configurations can be done based on their different shortcomings what is coming during the reactions when applying for chemical engineering processes.

So, there may be you know that sometimes mechanical agitation, sometimes it will give you the more energy requirement and also you know that there will be internal circulation of the liquid. So in that case to avoid that circulation of the liquid or fluid medium there sometimes you know the channel based monolithic reactors are internally placed so that mechanical agitation part should be avoided there, so this type of configuration is there.

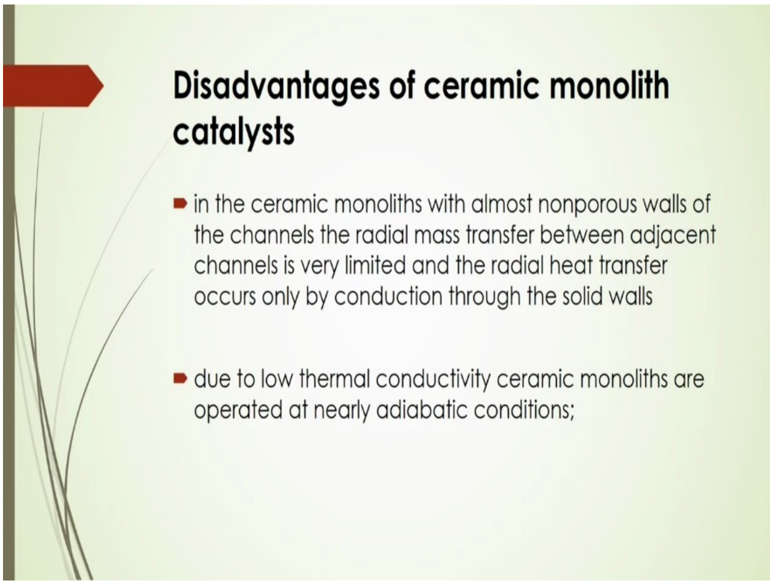
So based on that, different shortcomings and how it can be actually optimised and based on which that the adaptation of the design of monolithic reactors are coming in the present here.

(Refer Slide Time: 45:57)



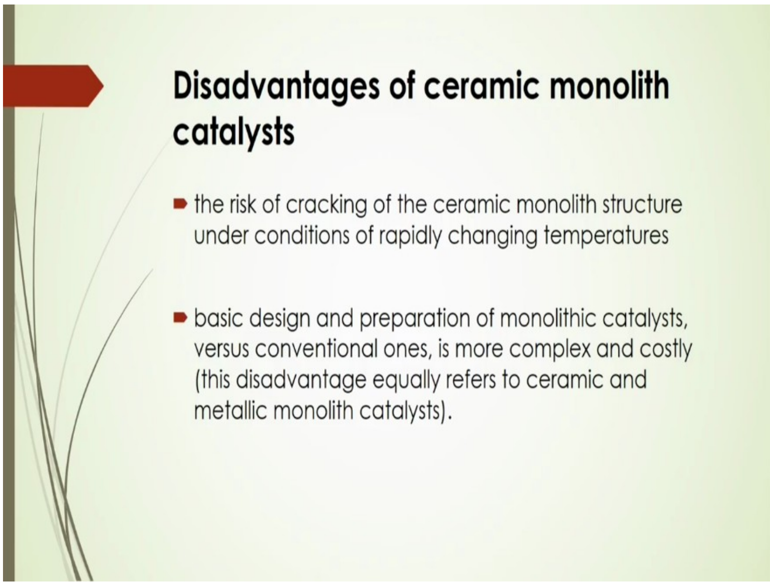
Now, question is that what are the advantages related to conventional catalysts? If you are using that monolithic catalyst, then what would be the advantages over other conventional catalyst? So the most important advantages of monolithic catalyst are the high specific surface, small pressure drop, good interface mass transfer, good thermal and mechanical properties, simple scale up and other advantages over which you can make them superior related to conventional catalysts there. So these are the different you know that important advantages of monolithic catalyst.

(Refer Slide Time: 46:39)



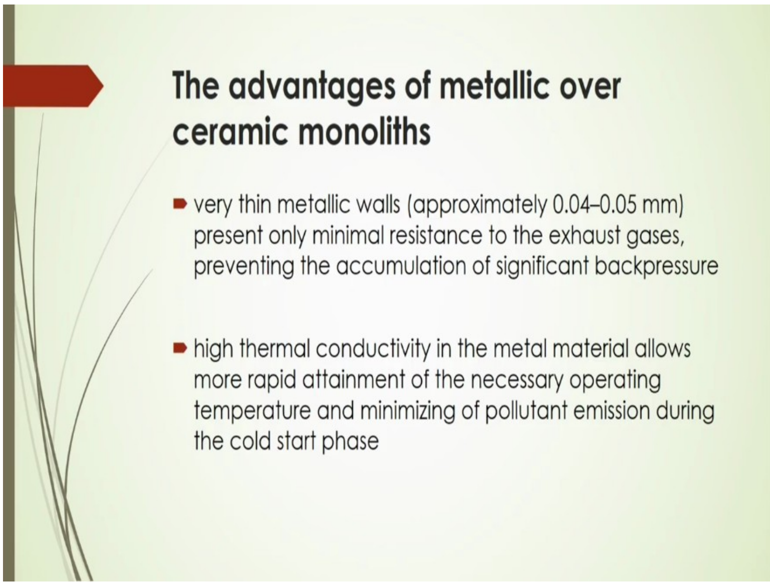
But parallely you will get some disadvantages of monolithic catalyst, sometimes if you are having ceramic monolith, in that case you know that almost nonporous walls of the channels, the radial mass transfer between adjacent channels will be very limited and the radial heat transfer occurs only by conduction through the solid walls in that case, it is not actually suitable for chemical engineering reactions. So due to the low thermal conductivity, ceramic monoliths are operated at nearly adiabatic conditions there, so these are the disadvantages of the monolith catalyst.

(Refer Slide Time: 47:17)



Also the risk of cracking of the ceramic monolith structure under conditions of rapidly changing temperature are there. Basic design and preparation of the monolithic catalyst versus conventional ones is also more complex and also it should be cost-effective, so that is why the disadvantage equally refers to ceramic and metallic monolithic catalyst are there, so these are some disadvantages you can say.

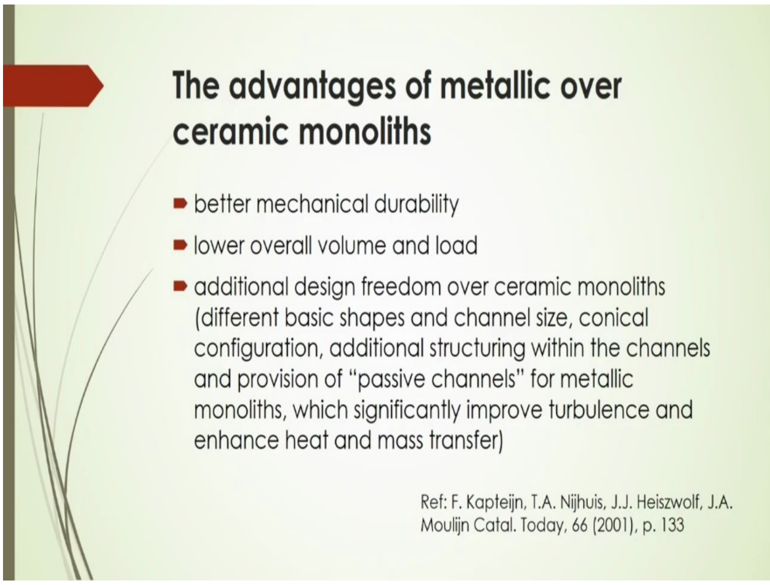
(Refer Slide Time: 47:47)



Whereas, the advantages of metallic over ceramic monoliths also will be there because there are two types of monolithic reactors are being developed; one is ceramic monoliths and another is the metallic monoliths. So in case of metallic walls, in that case very thin metallic walls approximately you can say that 0.04 to 0.05 millimetre presents only minimum resistance to the exhaust gases that prevent the accumulation of significant back pressure there.

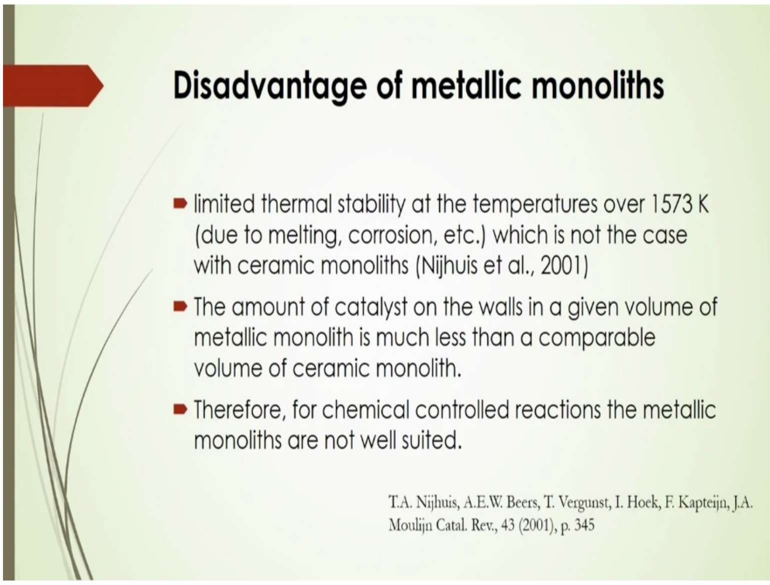
And high thermal conductivity in the metal material that may allow more rapid attainment of the necessary operating temperature and minimising of the pollutant that emits during the cold start phases. So this type of advantages of metallic over ceramic monoliths you can have.

(Refer Slide Time: 48:47)



Also you will see that the metallic monoliths also have better mechanical durability, lower overall volume and load, additional design freedom over ceramic monoliths will be there. There may be additional structuring of channels and provision of passive channels for metallic monoliths will be there so that may significantly improve the turbulence and enhance heat and mass transfer in the case of metallic over ceramic monoliths there.

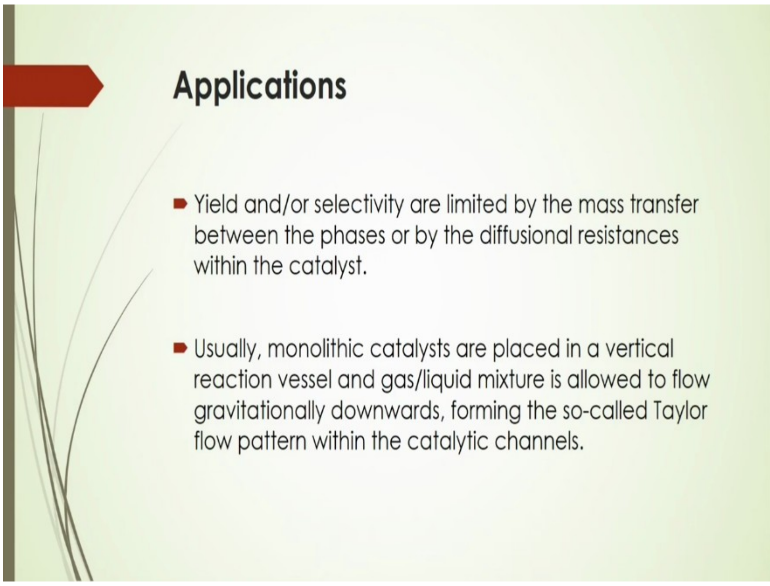
(Refer Slide Time: 49:20)



Some disadvantages also will have this metallic monoliths. In this case, limited thermal stability at the temperatures over 1573 K due to melting, corrosion, et cetera even which may not the case which ceramic monolith there. And amount of catalyst on the walls in the metallic monolith structure in a given volume of metallic monolith is much less than a comparable volume of the ceramic monolith.

Therefore, for chemical controlled reactions, the metallic monoliths may not be suitable compared to the ceramic monoliths there. So these are the points that you have to remember, why this metallic monoliths will be more advantageous than ceramic, and also why it is not advantageous in the particular cases like high-temperature is there compared to the ceramic monolith there, so that should be considered during the design of the monolithic reactors.

(Refer Slide Time: 50:27)

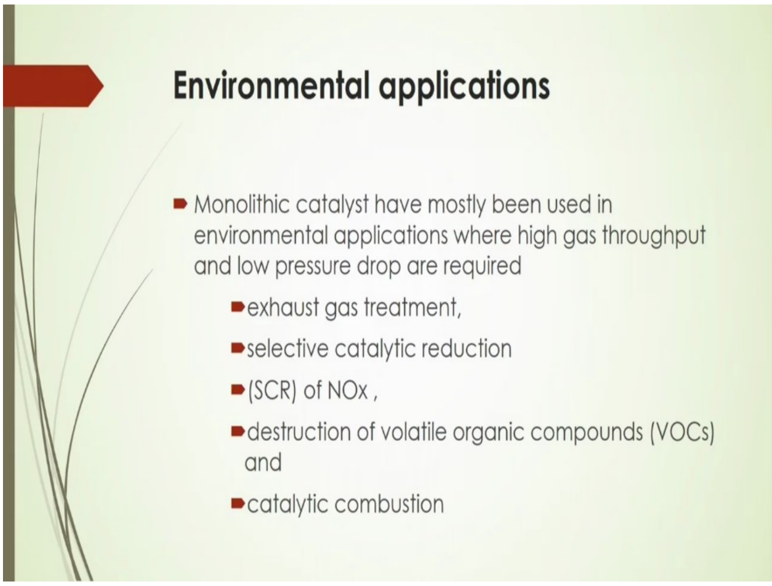


Now, you will see there are several applications of different types of monolithic catalytic reactors. In this case you will see sometimes yield and selectivity are limited by the mass transfer between the phases or by the diffusional resistances with the catalyst. So based on which, based on mass transport, hydrodynamic aspects, diffusional resistance, all those things, there are several applications of monolithic reactors, where that yield and selectivity should be considered for the particular applications whether it will be coming that intensified way or not.

And usually you know that monolithic catalyst as an examples are placed in vertical reaction vessel and gas/liquid mixture where it is allowed to flow gravitationally downwards and forming so-called that Taylor flow pattern with the catalytic channels. So in that case hydrodynamic based monolithic catalytic reactors also to be developed so that whether you are getting that particular suitable flow pattern for that reactions or not, like you may get honeycomb structure monolithic reactor there you may get flow pattern of Taylor flow pattern that means here slag type flow pattern will be there, elongated slags will be there.

So in that case how the surface actually is giving the interfacial area to give you mass transfer benefit over there just by diffusional less resistance over the surfaces. So in that case, this hydrodynamic aspect is very important, so based on that hydrodynamics even that catalyst types that different applications of this monolithic structure will be there.

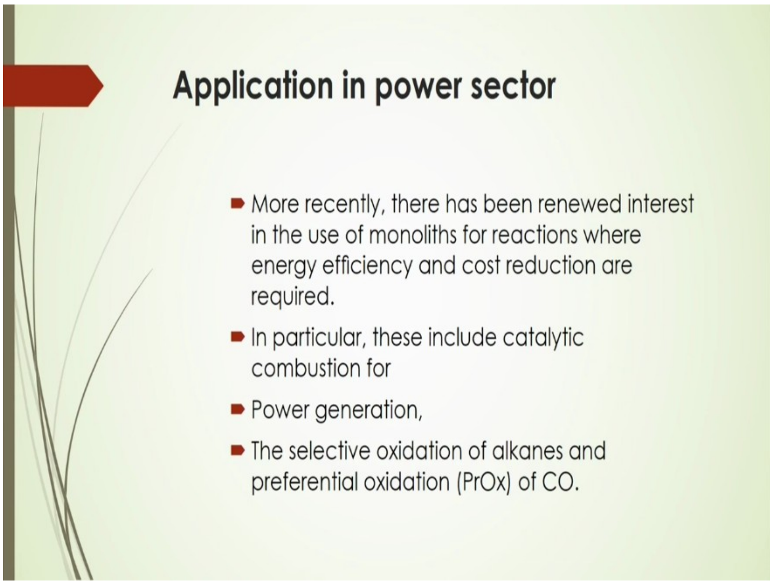
(Refer Slide Time: 52:22)



There are several applications in environmental some you know that remediation like monolithic catalyst are mostly been used in environmental applications where high gas throughput and low pressure drop may be required in that case, exhaust gas treatment, selective catalytic reduction, even you know that NO_x gas reduction, scrubbing of that NO_x gas, destruction of volatile organic components there, even combustion reactions also are there, so these are the several applications are there.

Even in power sector also more recently there has been reviewed interest in the use of monolith for reaction where energy efficiency and cost effective reduction of exhaust gases and also reactions for the power plant to produce different gases and how it will be used for power generation there.

(Refer Slide Time: 53:46)

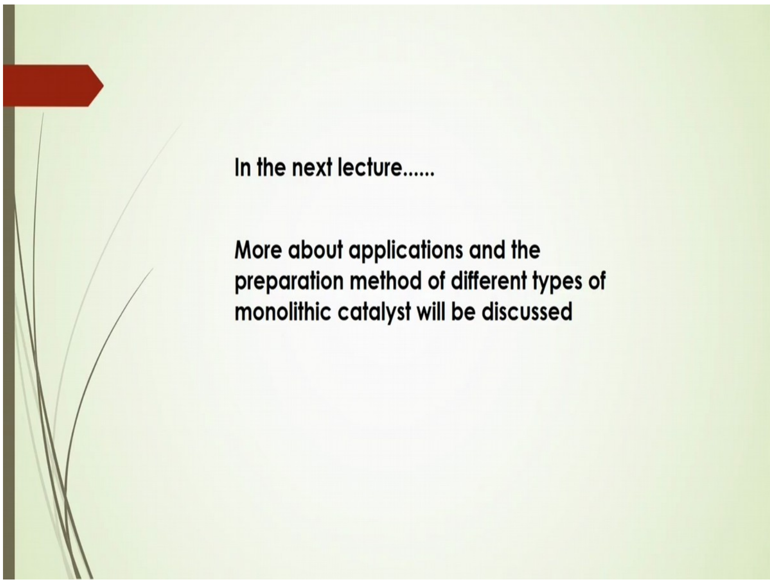


Because the combustion will be catalytic, and also generation of the steam from water will be one important aspect there. So power generation, selective oxidation of the Alkanes and preferential oxidation of carbon monoxide based on that you know that energy efficiency process by monolithic reactors are being applied in particular this power sector. So that is why the applications in not only in environment, some other chemical engineering processes also like you know that Fisher-Tropsch synthesis, there gas, liquid, solid reactions are there to produce different types of hydrocarbons, so there these monolithic catalytic reactors are important.

So earlier actually the conventional way like in slurry reactors that gas, liquid, solid they are actually moving inside the bed that is arbitrary that is the internal circulation of the fluid medium to get that well mixing there, but sometimes back mixing may hinder the reaction performance. So to remove that back mixing, this monolithic reactors are coming.

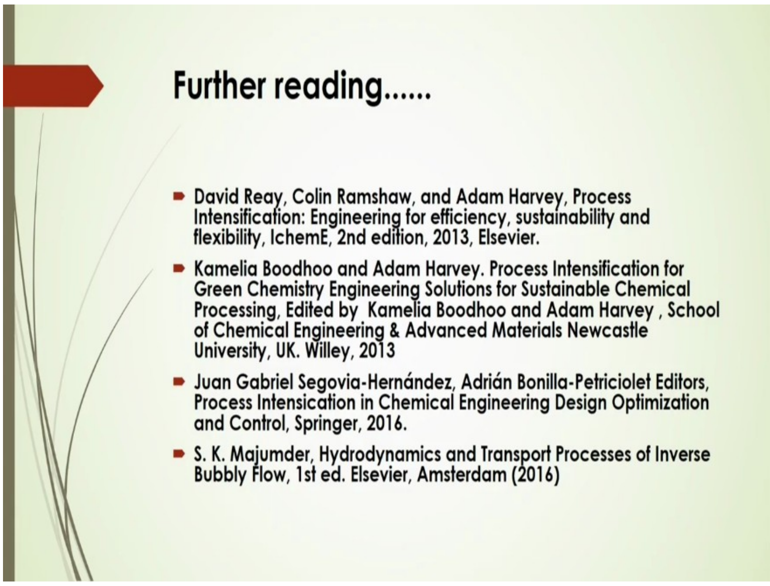
Even to reduce the radial movement of that slurry fluid, there also these monolithic reactors are being actually considered to get the more efficiency of the reactions. And they are also that other oxidation reaction also based on the monolithic structure just replacing that mixing of the fluid flowing through the channel based monolithic reactors are there.

(Refer Slide Time: 55:09)



So, in the next lecture we will discuss more about the applications and a preparation method of different types of monolithic catalyst.

(Refer Slide Time: 55:15)



And I will suggest to go more about the different types of monolithic reactors, even what are the different structures of that monoliths to go through these textbooks there, so thank you for this lecture today.