Rheology and Processing of Paints, Plastic and Elastomer based Composites

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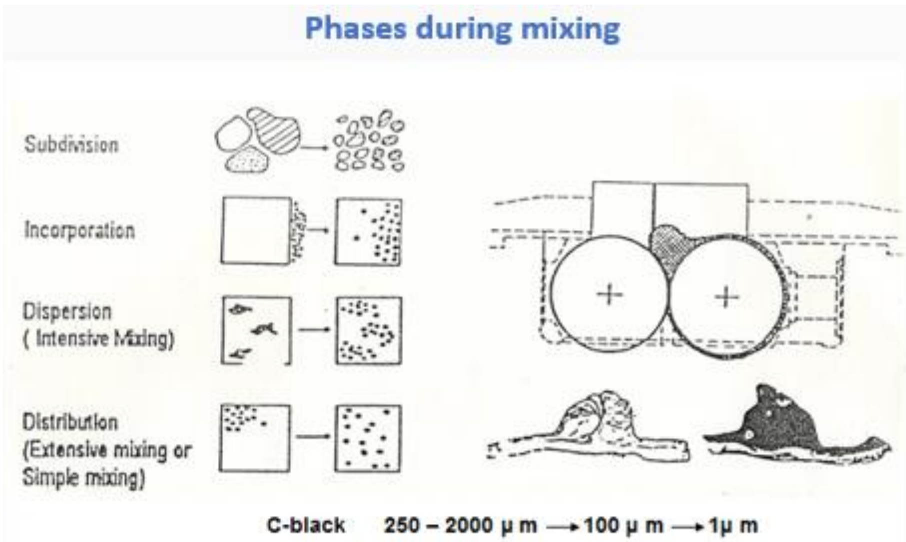
Lecture 32
Various mixing equipment and their importance

Welcome to the NPTEL online certification courses on the rheology and processing of paints, plastics, and elastomer-based composites. Today we are in week 6 and its lecture number 6.2 and we will get familiarize with different mixing equipments at a glance. Once again what I am going to cover what is mixing and then mixing equipments for particulate mixing and then we will take it forward from the perspective of melt mixing only that means at high temperature mixing and that is commercially being practice. I am not going into the other 3 4 different types like lattice stage and solution stage part I am not going to talk about here. And then 2 roll mill and internal mixture which are the you know heart of the rubber mixing basically and then bit on continuous mixers which are not very common, but for distributive mixing it is practiced.

These are some of the keywords including centrifuge impact mixture which is high intensity mixture mostly covered for PVC mixing then concept of Weber number and then bit on brevender kneader you know tangential intermeshing type of things co-rotating counter rotating extruders and then intermeshing non intermeshing type of designs basically. So these are some of the keywords. So what is mixing? See mixing you can say a process to reduce compositional heterogeneity or non uniformity by a relative motion of the 2 components. See suppose I give you a red color marble and black color marble I give you a bucket.

So how to do it effectively and I give you another place where you have to make it randomized or reduce the in homogeneity. So you have to pick one red one black one red one black and try to make put them in a in a lattice structure basically in a particular form either 2D or 3D form of it. So practically that is what you have to do. Two polymer systems and or polymer and an enforcing part put them together try to apply shear forces have a laminar or you know turbulent flow set in depending on what you exactly want to do and then try to make them homogeneous eventually. So let us take some combinations what is commonly being practiced if it is solid-solid combination what is a solid-liquid combination it can be liquid-liquid combination it can be liquid-gas combination liquid-gas combination is typically when you make you know forms basically.

So then those are the examples given here. See now well before you know understanding the mixing hot of the mixing see first part is a subdivision if it is a filler in the form of a lump you have to subdivide it. Second part if you have a continuous polymer matrix filler is a reinforcing unit part it has to get incorporated the second step. Third step this aggregated structure even if you break it is still aggregated structure it has to break apart and come to the primary or smallest possible size you call it a unit called dispersion and last but not the least part of it. Even if you have a small form of it it should not stay at one of the corner other corner stubs it should be homogeneous everywhere.



So these two basic part dispersive mixing and distributive mixing is actually hot of polymer mixing. So you have both of them together simultaneously done if you have a good distribution but not dispersion property will be inferior and if you have a good you know distribution but not dispersion you will have a flow points everywhere. So again property will be bad. So at the end you have to achieve both dispersion as well as distribution when we talk about a mixing to reduce the compositional you know non uniformity. So you have to achieve this thing simultaneously.

So let us try to take some example then that we practically practice for solid-solid, solid-liquid or liquid-liquid combination in order to achieve both dispersion as well as distribution. First try to see from the distribution point of view and then try to see from the dispersion point of view but remember in our cases for the polymer brains and composites we have to make both dispersion and distribution at the end that is the bottom line. So when I talk about a distributive mixing maybe you might have seen in the roadside when people are using bitumen and concrete and they have a gravity mixture tumbling mixture. You have a brain mixture you have a air mixtures. So these are all basically for distributive mixing you are not anyway breaking out the concrete there.

So these are some of the example you might have seen it in the roadside when a big drum is rotating and people are pulling in bitumen and concrete and eventually they try to make the road. So those are some of the classical example with different design of course you may have a shear you have a shear and torsion and different types of force that is how the different sort of a boil design changes from one to the other. Another is a blade or a rebound may be placed while mixing it. So it will give you even more a homogeneity essentially and you can use fluidized blade type of a mixture also in certain cases. So all these things are giving a kind of a distributive mixing.

On the contrary the last one if you have a impeller that impels very very high speed and you have a very hard and tough and you know strong wall and it impulses and it gets dispersed. So some of the cases like high intensity mixtures where the impeller rotors at around 2000 to 4000 rpm. PVC mixing particularly centrifuge impact mixture is the example high intensity and centrifuge impact mixture it takes care of the centrifugal force. It rotates and it actually allows it to have a collision with the hard surface of the wall and it can be a thermokinetic mixture like this where you have a shaft one of them may be may be stationary other is rotating. So this sort of a you know brute forces actually enables you to cross the the filler aggregates which are primary particle size is so huge.

They never stay in the primary particle they remain try to associate it in the form of aggregates and that aggregate remember you are trying to break down while mixing. So another thing every day you see may be older days in the kitchen household people used to use motor vessels. So what it does actually it crosses so crosser mills roller type a roller crosses flat support of it jet mixer there is a jet a higher jet and that takes that particles together and try to have a collision. Another part is ball mill between two small size different balls small size balls in presence of surfactant and without presence of surfactant it rotates at high speed and try to giving you you know particle size reduction down to nanometer primary particle size those are called ball mills. So those are about the solid solid you know dispersive mixing up till now.

So solid solid distributive dispersive I covered up. So another part if it becomes solid liquid then it becomes very difficult because if solid is suspended in liquid no way you can put the hammer and trust it your force has to transmit through liquid to the solid. So in that case you have to take advantage of surface treatment you do prepare the solid make it more wettable so because of the hydration or solvation force it comes out from the aggregates automatically. And then that way you do the size reduction you have a internal drag turbulence etcetera etcetera. So remember for liquid case if I want to look it at from the distribution point of view it must be a laminar flow you just try to speed the you know flow areas basically and then try to reunite.

But when I talk about dispersion of a liquid I have to really have a turbulence I have to really stretch the liquid to a form of a ribbon maybe you should try to assume and then because of the surface tension forces and balance between surface tension and interfacial forces it has to split. Miscous force and surface tension force. Miscous force means you are generating that shear forces. I am coming there I mean this ratio is called Weber number. So that helps you understanding with which shear forces what should be the droplet size you can generate minimum particle size.

So liquid-liquid dispersive forces again if you have to generate you have to stretch the fluid you have to really create events of turbulence basically. So distributive vis-a-vis dispersive. So this is the number called Weber number which is nothing but you know it is a interfacial force in the denominator in the numerator it is it will be dot. So eta into comma dot what is that shear stress. So shear stress caused by interfacial tension.

So if shear stress means the brace is further split, it interfacial force means the raise you would not be able to split it further with a given you know shear rate. So that is how you can decide which shear rate you need to which rate of range of dispersion you want basically. So this Weber number you must not forget okay you may expect some numerical in your examination invoking the Weber number. So now if I consider a rotor you have a two polymer molten polymer I am trying to have a mechanical rotor that I still can achieve with a agitated type or anchor type of a rotor only and only when my viscosity is less than 10 Pascal second but a real polymer polymer melts or soften rubber it is anyway greater than 10 it is typically 100 Pascal second. So you call it a like a viscoelastic fluid or solid.

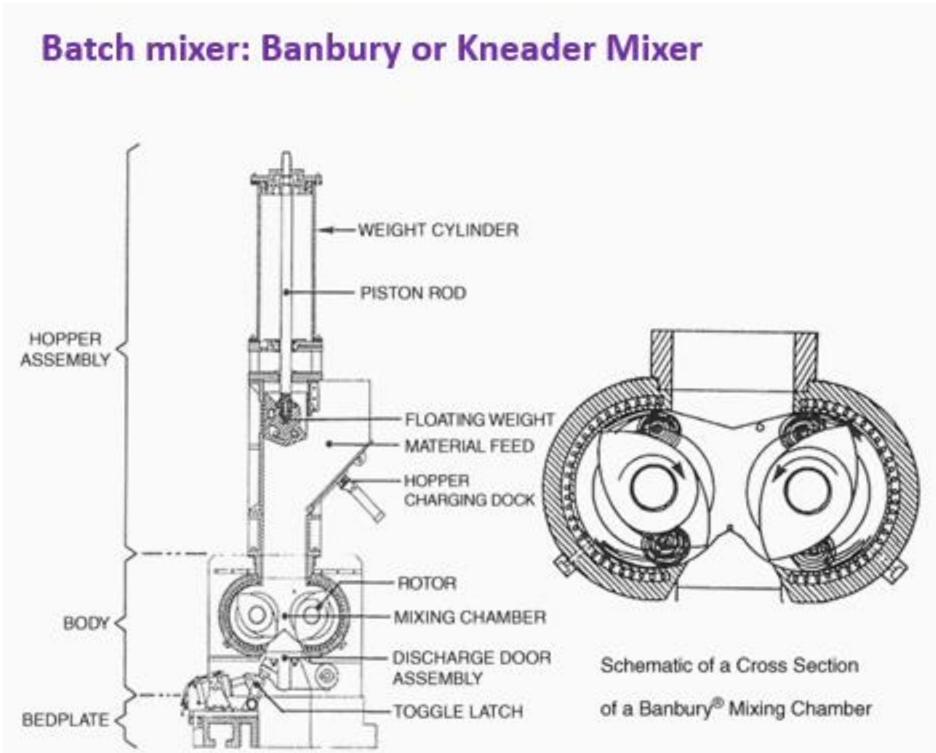
So in that case using a mechanical agitator it will not rotate further your motor will burn okay. So maybe in the solution phase two polymer you can you can mix them okay but you cannot do it in solid state with that kind of mechanical stirrer even if you increase the temperature. So you have no choice other than going for certain other equipments. So two choices for rubbers or viscoelastic fluids are two roll mill which is open mill to oppositely rotating in a cylindrical metal frameworks. In other case you have a confined place where you have two rotors rotating in opposite direction and you push your polymer and try to do it.

So both of the of the of the processor batch processes only okay but you have a option for other sort of a polymer like plastic say for example. In that case you still can afford to have an extruder. So now question is that why not extruder for rubber mixing. The reason is that kind of a heat it generates in a twin screw extruder okay and rubber particularly remember what I told is a reactive mixture it has it is a prone to degradation at high temperature number one number two it has active ingredients like curatives accelerators. So unless you cool it very quickly you would not be able to you know keep the material after mixing tossing that is very important.

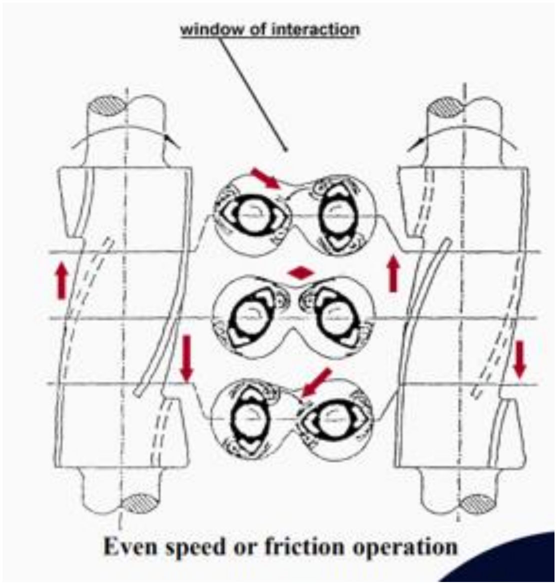
So that is the reason why in dispersive and distributive mixing if you wish at all particularly dispersive mixing can be only and only achieved in two roll mill and as well as the internal mixture not in the extruders okay. So these are the choices. So I am not going into the kneader I will talk about kneader at the at the end but twin screw extruder remember is a workhorse for plastic industries and internal mixture is a workhorse in the rubber industry. This is the two major equipment for mixing you always remember that and here you have a two roll mill you are trying to form a you know stitch here. So what is important if you have two rolls this is very important the nip gap gap between the two roll surfaces number one.

Number two roll rotational speed and in two roll mixing actually two roll rotates at a different differential velocity or rotation rpm and that is what is called friction ratio number three and of course the roll temperature it depends much on the cooling the temperature one relative to the other and the polymer I will explain in details I mean handling a polar polymer in a in a you know two roll mill and making sure it stays in the front roll front roll means slower roll is often a difficult challenging task unless you you understand his physics okay. So I will make you understand what actually it happens in a two roll mill how you make sure it stays good up to the end of processing end of mixing. So roll mixing the process variables for a roll mixing are most roll mills have all the affix speed and affix friction ratio consequently the actual process variables are the roll temperature and nip gap and by nip gap adjustment one can see another thin nip gap you can afford to change it say for example while filler mixing you have really large you know nip gap okay and then you close it for that for the dispersion okay make sure it disperses well because you would like to smaller the gap larger is the shear forces for imparting mechanical forces but while mixing the q rate is of course whatever you have to increase the nip gap so that the temperature increase will not be that fast okay you have whatever cooling opportunity you have you will be able to pull it for cool it down. So those are the things you have to keep it in mind. So two roll mill of course is a manual one so open roll it has a pollution hazards because carbon black silica you add it those are very fine size I mean once you fall it it can it can fly in the air actually okay.

So residence time control, mill temperature control, dispersive mixing achieved by nip adjustment that fine-tuning shear is only delivered through the nip rolls areas okay and sometimes if you not as I said dispersive mixing is a brute force, distributive mixing is a small force. So you often have to have a combination you have only brute force you disperse well but end up having poor distribution that you have to keep it in mind that balance is important for the quality consistency and that is very difficult to have it manually achieved.



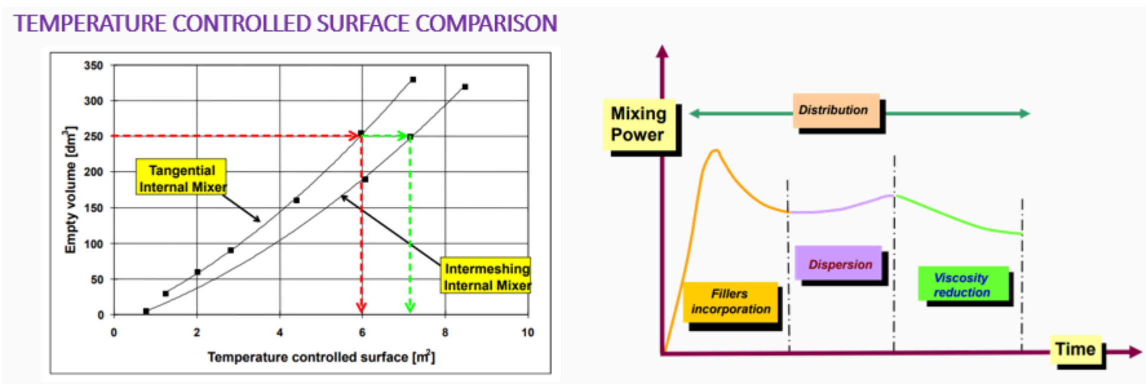
In Banbury or Kneader on the contrary you have precise process control your residence time is quite quite fixed you have every process control parameter all the machines today are feedback controls control so your energy input I mean energy necessary to mix it total input energy you can have it as a parameter so one batch to the other you make sure that much energy is only spent for so that your batch to batch variation will not be there. So this is the two things you can see side by side in a internal mixture exactly this is the heart of it you although you have a hopper you have a ram okay but ultimately where it mixes inside the cavity and of course you have a very good cooling system from the jackets in the rotor itself and even the RAM. So these three places in the RAM in the inside the rotor outside the rotor in the chamber wall you have a temperature control I mean water tampered water is flowing there actually at certain speeds to make sure all the hits that generates because of the viscous shear high shear or dispersion of the fill of particles that will be taken away.



There are of course different designs it can be tangential it can be intermeshing. Intermeshing means just try to look through my fingers okay these are two rotors imagine so if that goes radius of rotation overlaps you call it intermeshing so you have more nip action nip means minimum distance between the rotor on the contrary tangential they are parallel they do not overlap each other okay. So have you have more open space and of course dispersive brute force is more for intermeshing type of a design. So I am not going into that it again it all depends how many wings you have in the rotor it can be two wing it can be four wing nowadays six wing is also possible okay. So more this is the number of wing I mean more dispersion quality will be better and of course you need to have a understand in a mixing equipment unlike what I talked about a reometric measurements here one place to the other there is not a fixed shear rate it is a distribution of shear rate rather than a single shear rate okay.

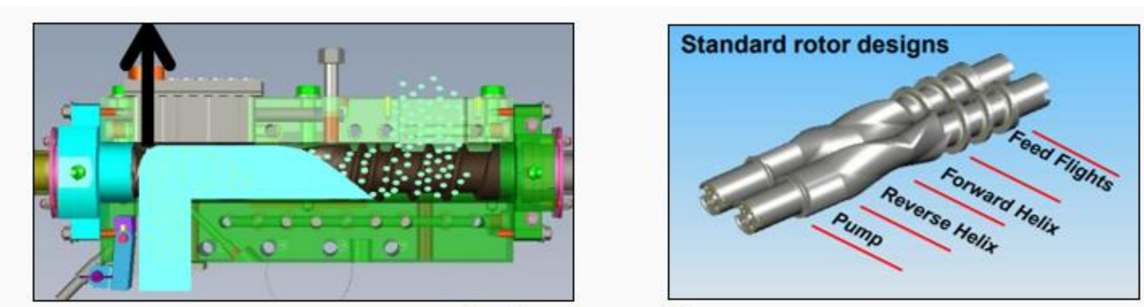
So that also you must have a control over that while designing a mixing equipment for performing the experiment of it. So there are certain exchangeable blades for Banbury type of a rotor Banbury is the name of the inventor actually eventually it was the company okay and then rulers sigma type rotor cam type of rotor all these designs are meant for generally Banbury type of a rotor design is meant for rubber mixing okay. So similarly camp of rotor type of a rotor a thermoplastic blastomer you want to make you go for that. So again a sigma type of a mixture fiber reinforced plastics you are trying to make so depending on type of composites blades what you are handling with your design of the rotor changes and your choice will change obviously. So the detailed depiction is given I am not going to read through and through anyway this will be shared with you please try to take some times and read through okay.

But most important points only I will highlight here okay Banbury is the internal mixture once again it is a name of the company by which it is called Banbury. So what is plus and minus control on the residence time compared to to roll mill okay of course per 10 or you know 5 minutes you end up mixing you know 1000 liters of rubber compounds okay. So if you are sick for such Banbury in your company that actually determines per 10 minutes multiplied by 4 into 24 hours into minute. So that is how we will be output and depending on your productivity can be determined you go to a company look it at looking at how many of Banbury they have you will be able to estimate roughly what is their production capacity okay. So nonetheless those are the some of the industrial part I am not going to touch upon here but nonetheless control over the residence time batch temperature control level of distribution and this partial mixings those are the most tricky things okay.



How to handle a tacky material which sticks in the rotor okay this sort of a things you have to troubleshoot. So I am not going to go into the details but those are the some of the things one must be familiar with or at least from the basic sense of rheology they should be able to implement it okay. So this is the window of interaction with the different speed how this arrow shows how the your material will circulate basically in between the rotors. So again if it is less than within 10 to 100 your kneader or dough type mixture is good but if it is more than 100 Pascal second your only chance is Banbury or Turol mill it all depends a small productivity often Turol is good it is longer time mixing though but it has more control over the Banbury but if you go a production like tire production and conveyor belts making so you cannot satisfy your productivity you will not be able to fulfill the amount necessary with the Turol mill alone you must have a Banbury there. So this is batch mixture technology intermeshing and tangential these two rotors I talked about choice is yours if it is industrial good you want more productivity go for tangential rotor design.

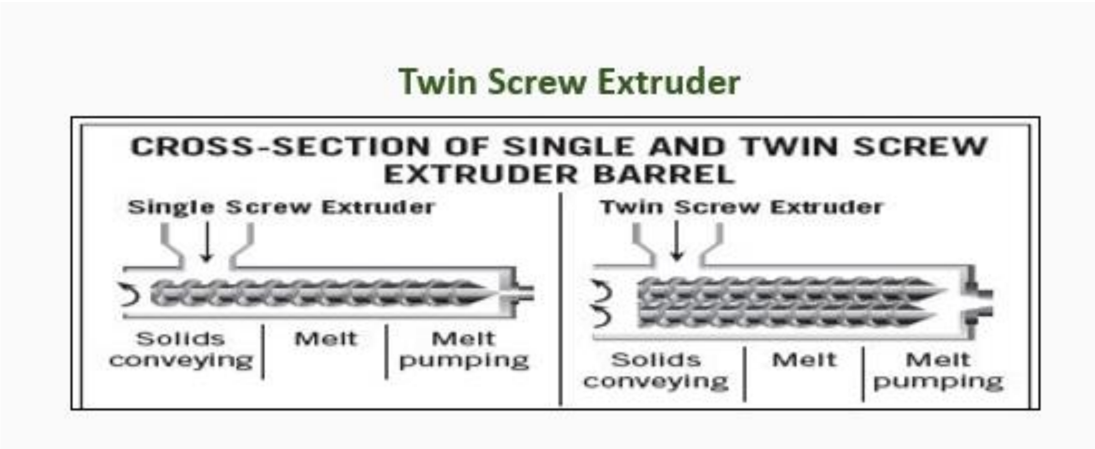
If you are I mean industrial good sector where aesthetics is good you go for a intermeshing type and what productivity is more like entire industries you know you need more surface obviously if you think about in a bowl if you have a intermeshing design it will occupy more space so you end up having less space for the rubbers to mix there so reason is as simple as that. So these are some of the flow patterns and the how the flow vortex are formed I mean I mean this is the nip action happening rotor and the chamber minimum clearances how the flow pattern you have seen some flow patterns like a parabolic flow pattern in 2D I have shown you again and again so now we can see how it actually happens I mean if you just have a 3D sense of it it's a kind of a flow generates and those are the major shear regions and which actually determines the milling zone and determines the major dispersion that you ultimately end up achieving. And these are some of the documents we found interesting so you try to go quickly click it on and try to read from there tangential intermeshing once again you can understand temperature surface control how much surface you are generating and that way intermeshing is far off while the empty space also you can see empty volume tangential vice a vice you know intermeshing type of a rotor design exactly that is what is happening so empty volume means volume available for the rubber to be mixed see at a given point empty volume is more for a tangential design you can see it from here while for intermeshing is less correct. So if you look it at the energy curve of it mixing power or you can you can put it absolute energy also over time we mix it ram is down and monitor after initial development of torque that means fillers are incorporating there will be a drastic reduction and this reduction signifies the dispersion events happening and then finally it actually has a continued almost constant viscosity and you are ready to dump your mixing is over here. So that is that much quantum of energy was spent having distribution actually happens from starting to end but dispersion happens in the first after breakage of the first maxima.



The Continuous Mixer

So heat exchange surface greater than 20 percent so one geometry to the other so that is how you can quickly compare intermeshing over tangential type of design. Areas of mixes applications intermix is one sort of a company and then you know manberry which is quite common for our mixing. So you can just see a comparison here intermixing what is specified one of the are I mean registered trademark specialty rubber and plastic as well extreme quality application reactive mixing and single step rubber mixing application whereas manberry high volume applications sticky material it can be dealt with even a multiple stage mixing is possible. This is the world's first manberry which was made it is a it is a it is a same as you know you can see the parity sugar cane juice you make it it is almost like that all day 1916 and where we end up today is very sophisticated state of the earth feedback control system ultimately. So these are world's first intermix which was again you can see 1932 and we are in 2023 now so can understand our machines are much more you know command control you can mix it remotely mixing will happen inside.

So continuous mixture is not meant for dispersive mixing for rubber these are reciprocative screw extruders kind of a what you put the material or master batches which is pre dispersed and try to make a homogeneous mixing. So from the two master batches you try to have a final batch intermixture I mean kneaders or continuous mixtures are good and it is called MBK extruding venting kneading or it is called like that you have a venting system you have a kneading system you have a reciprocating screw system and it is fitting conveying particle size reduction is very nominal though mastication is possible dispersive mixing I still doubt say it is a smaller extent as compared to a van very otherwise if you don't have a van very you have a continuous mixture then you have to bank on the van very people they will give you some master batches and use that master batch to final batch batch of these are some of the designs pumping action reversal extraction forward helix fit flight.



So that is the screw design and test screw design of the reciprocating screw extruder EVK extruding venting kneading that is how it is abbreviated. Single screw extruder means it is only one screw a single barrel. So you understand one thing it is a chamber you feed in the screw conveys once it goes screw gives you additional this action as well as rotational action.

So inside there you have the mixing achieved single screw in general as the application like pipe extrusion, feed extrusion, profile extrusion, modified compounding on top of that this EVK continuous mixtures. So you have a extrusion system you have a transmission system you have a heating cooling system embedded there. Twin screw extruder once again as you can see I am not going into the details of it but it is a workhorse of plastic industries. It is primarily meant for mixing stuff homogeneity and it is two types intermeshing and non intermeshing type of screw design and again it can be co-rotating and counter rotating depending on the two rotors weights functions. So it is a high torque it generate high speed low energy consumption high productivity.

So you have again in a twin screw extruder you have a conveying section you have metering section you have a plasticizer section and you have a final discharge section. So this is here and you can always refer to this link given over here. So I am not going into the details of it but again you can dig it in many of the plastic extrusion books essentially. So these are few of the references that I already talked about to conclude. I try to give you a glimpse on what is mixing, mixing equipments, a back mixing technology to all vice versa internal mixture including intermix as well as manbury and concept of continuous mixture and beat on twin screw extrusion.

In the next lecture we are going to go more focusing into the thorough and thorough mixing and what is the physics of thorough mixing what it happened how it mixes how you control with that. Thank you very much.