Rheology and Processing of Paints, Plastic and Elastomer based Composites

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Lecture 35

Introduction to Internel mixture Kneaders and Mixing using Internel mixture and Kneaders

Welcome to NPTEL online certification courses on Rheology and Processing of paints, plastic, and elastomer based composites. Today we are in week 6 and lecture number 6.5. It is all about introduction to internal mixer, kneaders, mixing and mixing using internal mixer and kneaders that is most important. So concepts covered internal mixer as I mentioned other day that it is a more controlled one inside a cavity although it is also a batch process. A continuous process is very difficult to establish like extrusion but kneader is somewhere in between.

But kneader is not exactly it does the case for the high intense dispersion mixing but relatively it can do dispersion but not to the extent of a Banbury although Banbury B should be capital is the name of a scientist actually. It is a internal mixer but there are different types but it goes all the way by the name of Banbury. And conditions for good dispersion in internal mixer, definition of mixing time, term criteria and some of the controls I mean how much time you work it for. As I mentioned it to you, your Banbury is a almost state of the art feedback control you know machine.

So you do not need much like in unlike in 2 roll mixing. So it is all PLC control or feedback control. So just in the console you give that you know command and then your automatically you know fillers are taken from the silos, rubber will be automatically fed although in the industries rubbers are fed by cutting and wetting it. But most of the other ingredients like oil is fed directly by pump inside that system. So it is all mechanized system basically.

Then about the keywords is something which you can use it for you know for your studies. But nonetheless here I am going to talk about not only the mixing which is unique in internal mixer you can follow four different sequences. You follow only one sequence in thorough mixing like say first add the rubber, then you try to add the filler, then you add the curatives and at the end. But that is the conventional sequence. But here you can do Ulta also upside down.

You add filler first then rubber because it is an enclosed chamber. And you can do as well as the late oil addition techniques and also the sandwich mixing techniques. So that I am going to touch upon here. But of course fill factor is another factor, another essential factor I will elaborate about. So here is a picture of a thorough you know internal mixture or banbury so called.

And although you from the cartoon you do not realize its height of almost a two storage or three storage building that now. I mean in ram stays in the maybe second floor, first floor you your things are fed and actually the ground near the ground floor is mixing happens. So some point of time you have the control system, control panel where you give the prompts basically. So it depends on how you try to do it. So as I mentioned you can read it like not only banbury you can read it like internal mixer that is better.

And kneeder I will put it in a separate category because kneeder has essentially in principle little different from internal mixer because it is not that intensive in the sense for the dispersive action it force. Whereas both banbury and two rolls can gives you that superior you know dispersion in things. So intensive and extensive mixing is important to understand. In internal mixer are designated to produce both intensive dispersive and extensive distributed mixing. Both the things are done.

Comparatively in either case you have a little less efficient you know dispersion. When I talk about SAF I have to you know use super abrasion furnace about average diameter 10 nanometers or little more. And you get a rubber which has a low viscosity. So that probably using a kneader, simple kneader you would not be able to do it. So in those cases otherwise functionally and all these three two internal mixer like banbury and kneaders.

Principally dispersion distribution everything you can do. And of course keep it in mind the you know mother is to roll mill. I will always say that way. First enclosed chamber in which you are trying to mix. You see the anatomy of it, cross section of it.

So this is how banbury or internal mixer looks like. A kneader where discharge is done vertically normally with the gravity discharge. It can be either discharge on a tandem mill with a ramless internal mixer or a two roll mill placed beneath that. And kneaders normally a side wise exit it has. It has a mechanism of reciprocating screw sort of a action.

Needing action mostly you have. So as you can see from here both of them having you know pair of rotors. You have a chamber wall, you have a floating weight you call it ram and feed hopper. These are the essential components of it. And all the difference

between geometrically if at a glance you can see in a you know banbury or internal mixer you have a vertical discharge, you have a discharge door.

Where the two roll separates them exerts action everything drops down after mixing. Whereas in this case it is side wise it comes out. So this is the full anatomy of it. This is the ram part of it. It comes closes ram up and down.

While mixing it should be closed. And these are the rotor it rotates. So you have a nip action between the rotor and chamber and in between the rotor also and this is the discharge door. And of course inside the rotor, outside the chamber, in the ram, the floating weight you put it you have a heat transfer system heating and cooling system there. I mean water flow lines.

So these are the essential component as I elaborated. Heating cooling is also very very important. Very precise control of temperature. Unless you do it I mean although it does it takes sometimes one fifth or one fourth of the time necessary to do the same mixing in two roll main. So you understand I mean how the first process is.

So effective dissipation of heat is very very essential. So condition for dispersion in internal mixer narrow clearance between the rotor. At this point I will tell you one thing. See if you see some dispersion problem over time after certain time first thing you must suspect there is a erosion happens. So if erosion happens too much then there will be more clearance between the chamber wall and rotor.

So obviously you will not be able you are not able to put in that much of high intense forces such as dispersion force. So tip and chamber wall that has to be monitored properly. Correct volume of loading. See fill factor is very very important. It varies from the rotor type to the rotor type.

Say intermeshing it already occupies lot of volume tangentially you have more free volume and say if I give you a glass of water little bit of sugarcane and salt. If you ask I give you full water and then ask you to mix a tumbling action it will never mix. So you have to leave some free space for mixing. So that is what the fill factor means. How much percentage of it is filled with the ingredients.

So it can be 0.8 fill factor means 20 percent is empty space. Empty space means rotor already occupied, material already occupied but still you have a 20 percent space left behind. So viscosity of the polymer low, polymer temperature and high viscosity and more prominent elastic characteristics of a raw material it all depends. So this is the figure the example of trend I have given you already. So it is a mastication followed by

incorporation.

So coming inside the matrix technically it came the fillers are most typical things. Then the dispersion and then essentially distribution and then you put in some liquid molecules as lubricants and essentially you try establishing the plasticization. So these are the unit process you want to have it that is the bottom line. So that is how coming from here to here is the actually ultimate time which you is necessary but technically speaking up to this you call it my dispersion distribution is achieved you define it as a mixing time. So this is the extra time it is up to you what type of a processing you are going to do.

Your dispersion distribution is over still you try to maneuver or manipulate you know rheological characteristics. So suppose if you are trying to reduce the pseudo-plasticity index width so work little bit on that try to add some lubricant there in the system. So I am not considering up to that so up to this dispersion I am considering it the unit process my mixing is over. It is then up to the your process or the other. So di-swell what will happen as you can understand with a mixing time it appears here if you are happy here but still if you can work on di-swell can be still decreased.

But again I mean allowing more time means more money why because that much of energy you have to spend on that that much of manpower you have to spend on that. So it is always a challenge why to you know stop your mixing. So you are satisfied go for the processing next. So another thing the bound rubber also bound rubber is an interaction. Filler goes to the dispersion maximum level so it forms a adsorb the rubber molecules and forms the rubber bound rubber.

See the bound rubber is already established here why to spend unnecessary this much time. So that is how you define mixing time correctly. So that is what the dump criteria my mixing is done in an internal mixer. How to dump? There are three different ways criteria by which you can dump.

Number one temperature based dumping. Number two torque based dumping. Number three energy based dumping. Nowadays energy based dumping that means how much electrical you know power it is consuming. So based on that you dump it. Remember commercially these are all commercial equipment specially kneaders and internal mixer heavily.

So when you pay electricity bill you pay in the form of how much BOT you spent and also the peak power maximum power you withdraw. Suppose you have a four banbury in the industries. So you have to really stagger it otherwise if all the four machines the peak

dispersion, peak power means dispersion time it consumes maximum energy goes at the same time you have to spend maybe four times the power electricity bills. So those are the other part energy balance etcetera etcetera. This is the curve it explains it can be torque versus time.

See initially what happens you know it is a bold line means different types of filler filled system. If it is a reinforcing filler initially the torque gives you maximum torque after ramp is down. That means rubber started entering into that boarding of the train happening. Then after that after incorporation is complete one it goes to a peak here and the peak is due to the dispersion. Then after the seal dispersion distribution continues after a while torque goes a plateau value and that is the time when you should dump it ideally.

And now what if this is a non reinforcing filler so its dispersion is not that well visible at least from the torque based monitoring system. So in this case also you can monitor energy also. See electrical power what it is consuming. So that way you also you can select in dumping criteria. So energy of mixing operating with the power integration quality control that is now it is done.

Maximum power is incorporated in the incorporation and dispersion that part. So sometimes how do you manage you try to use some dispersion promoter. So if you do so wetting will be faster incorporation will be faster and not only that dispersion also it will not go through that height a peak maybe it comes from somewhere. So that way you saving energy. So this is what a entire rubber a power curve for a entire starting from the mastication to black incorporation it power shoots up incorporation happening.

And then once you add oil naturally the power consumption reduces because of the slippage and lubrication and then again it goes to a peak power and then you know optimum dispersion is over you reach to a minimum here. So almost plateau value you reach it. So accordingly you have to optimize and do your you know energy base mixing. Temperature control facility as I mentioned it plays significant role. How it is being done? It is very depictive and not going into the details.

Please read through these things will be supplied to you. So this is how the temperature control essentially it is a spray based technique. What a jet how it goes basically I mean what gives you efficient pumping etc etc. But nonetheless from the cartoon you better understand it here.

See it is a sprinkling system basically. So it goes through it actually sprinkles and this is a wing part of the rotor. Where you have the maximum you know heat generation why

maximum shear because that has a minimum clearance with the chamber wall. So you can always consider the or the documents we got it from the internet. You can go for the details of it.

So for the timing I am not going into the details. So this is a typical you know circuit water temperature circuit heat transfer system in a mixer. So how the water is going is getting converted to steam taking away the heat and coming back and dumping into that system and all together that you can say circuit basically. Circuit has a pump which circulates the water like a hot. This takes care of the major path of it.

So everything should be feedback or feed forward control. Control system is very important because night to day there will be fluctuation. So accordingly it should adjust the you know cooling system. Remember on the surface I want plus minus 1 degree or plus minus 0.5 degree control. I do not know how many of you are familiar with the control system.

So I am not going into the details but as a chemical engineer you must know different types of control system PID control, feed forward control, feedback control system how it works. At least PID control you must know as a beginner. So if it is a power law fluid is tau equals to k into gamma dot to the power n. So what I mean by low intensity mixing is I am considering 100 to 250 second inverse. But when I am actually talking about high intensity mixing it is about 200 to 600 second inverse.

$$\tau = k\ddot{\Upsilon}^n$$

So you can anticipate and gamma dot as I said initially velocity divided by the linear gradient basically velocity gradient dv/dx. And of course the shear rate is directly proportional to the rotor speed and inversely proportional to rotor clearance. Rotor clearance less means high shear rate. And then in areas far away from the rotor tip shear stress are minimum and that is the blending action, distributed action. So one thing you must know in between two rotor there should be a very good circulatory flow.

$$\ddot{\Upsilon} = \frac{\mathrm{v}}{\mathrm{h}}$$

If there is no circulatory flow pressure will build up and there will be distribution problem will happen. So these are the nitty-gritties while designing. I am not going into that aspect how to design a rotor. That is also a complex rheological problem. So you can calculate the total strain and the rotor speed is also very very important and this is the plateau temperature with the rotor speed.

$$s = 2\frac{b}{h}$$

With the rotor speed obviously as you can expect. What do you expect? If you have a higher rotor speed more nip action. More nip action means more heat generation. So you see here there will be more or less a linear response. Ram pressure plays very important role. Ram you understand one which was on the top and while mixing comes down.

See ramp can be fit in very tightly with a high weight. Anything cannot escape. That is one condition. Second condition ramp is dancing as your material coming pushing it going up and then down, up down. So you have additional kneading action and that is necessary. If you have a kneading action then only you have additional distribution component and if the ramp is sitting somewhere up it does not ever touch the material that is the worst situation.

So you can monitor if you have a little torque meter on the tip of the ramp. So this is little oscillation means your ramp is going up and down. No force here, no oscillation here means ramp is somewhere at the distant place and more oscillation means it is tight. It is not allowing material to come out of it. So these are some of the criteria by which and of course the cooling efficacy you always repeat.

Mixing temperature exerts a very appreciable effect on the rheological properties that you have to be very clear and you can use the Arrhenius type of equation just to calculate roughly with the viscosity how it, how viscosity changes. Viscosity changes with the, if you increase the temperature obviously viscosity drops down. Viscosity drops down mean dispersion efficacy will go. So that you have to keep in mind. So, it is at the same time not only the ramp you have to take care of the cooling efficacy also into account.

$$\eta = A\exp(E/RT)$$

But I will show you one of the programs like I said in internal mixer you just simply put the program. This is the temperature based dumping system. In the console you program in such a way that different temperature you define and in those temperature your ramp will come up and down, up and down and finally you get the discharge and that will assure you, guarantee you the mixing. So remember one thing there are many types of one pass or multiple pass, single pass or multiple pass.

So suppose if you have a very, very highly small sized particle. So if you just try to put curatives along with that in same stage try to mix while breaking down of the aggregates

temperature will be so violent that scorching will happen. So if it is the case you have to do in two stage. First stage finish the only rubber and filler and whatever it is then dump it, pull it down, put it back at a low RPM in a controlled condition try to mix the curatives. So that essentially count the two pass mixing.

So sometimes there are three passes also. Remember one thing before I forget if you have a silica, silica is quite common in rubber industries. But silica being a harder material it erodes wear and tear of the rotor tips will be more. So you have to have a more observe on that I mean take it care otherwise there will be dispersion issues come up faster than the carbon black system. So normally in those industries silica based banbury are kept separately so that you can have a more you know vigilant on that survey I mean you should notice it, it is how the wearing pattern so that you can better do it.

So this is the torque curve for the mixtures. As I already mentioned I am not going into the details but if you just monitor the microstructure of it, from here to here you see whatever I showed you in a schematic way exactly that there is a lumps are there and those lumps are breaking down, breaking further down and essentially you have a better dispersion with the increasing compounding mixing time basically. And in torque wise also same reflection will be happening with this microstructure. So quality control although in rubber industries we do it with the dispersion grader but that is not absolute for better development you have to monitor with, the high end electron microscope or microscopic monitoring with the mechanical monitoring. All the you know internal mixers as a automatically give you the signatures of mixing you must record it so you can do the post mat in any point of time where it goes wrong. Some batch is giving you bad results so you can immediately troubleshoot online and offline control you can do it.

So these are the some of the technicalities from the point of view of as I mentioned you can practice four different sequences conventional I am not going to elaborate about that rubber first and then filler, filler half filler 50% of filler then mix it well then rest half 50% of filler and then oil, oil is typically 10% with respect to the filler. Then you try to put in the other ingredients initially you put antioxidant, zinc stearate, zinc oxide stearic acid along with the rubber and then finally you try to put in accelerators, activators, accelerators primary, secondary and last but not the least you have to add the vulcanizing agents that is the common sequence you follow but exceptions are there for nitrile rubber you try to add sulphur at the beginning and control the temperature reason is what why sulphur does not mix well with. So whatever there is a thumb rule whatever is difficult to mix that has to be added first so that entire mixing sequence it takes that means more deformation, more shear rates it faces. See say for example if you have silica and carbon black, silica dispersion in a in a gel purpose rubber is difficult compared to the carbon

black so you try to add silica first and then carbon black. It is a hardest nut to crack you have to crack the hardest nut, followed by the others so that is how the common sense.

So then rapid oil addition early oil addition method or late oil addition method see if you add oil what happens viscosity goes down if viscosity goes down, can you do efficiently the dispersive mixing answer is no. So in that case you have to add oil late at the later stage and upside down is ultra reverse so what you do add filler first apparently filler you were adding later so all the dry ingredient first including curative everything add filler. So you normally practice it for highly loaded system like a EPDM is most quite common. So these are the things but in that case you will not get very good deal of dispersion upside down is too bad will be too bad for dispersion point of view if you are bothered about the dispersion. So various types of things are written here you try reading through, it is all about the process nothing very very you know hard and fast to describe but nonetheless what is important here this all these four different sequence you can afford to practice in a internal mixer which in the other hand you cannot do it in a two roll mill.

So this is very important degree of fill this curve try to understand one thing this is a mixed quality plotted in y axis x axis degree of fill that is a fill factor. So we try to practice in three different RPM of the rotor 25, 38 and 63. So try to observe one thing as we are increasing see you see here it is a opposite way in this direction 6 means it is a poor mixing poor quality inferior quality and this is a superior quality So you see as you increase the rotor speed the best quality is the minimum obviously and is coming towards is a less fill factor size. So that means if you have a rotor speed high your fill factor should be low why if your rotor speed high your virtual volume of the material increases if I move around rather than static so I am occupying more volume. So that way it will head towards lower fill factor so that you have still empty volume more and another thing if you increase the RPM temperature rises faster.

So these three things has to be kept in mind and this curve very nicely explains how do you pick choose between the different parameters correct. So this is what I am not going into the lot of rheological part of it like unlike I talked about for the two roll mill but it is also a complex fluid flow. Just for the beginner as I intend to design this course for the beginner, I am trying to talk about the one which is practice why it is practiced. Advantages there are many safer cleaner healthy because nothing it is a enclosed chamber wide range of mixing sequence that I told you shorter mixing time 5 to 6 minute which we otherwise can take all the way 30 minutes 40 minutes in a two roll mill better and more uniformity reproducibility more control. But there are certain batch to batch variation normally does not happen if it starts happening it happens more reason is that say for example, if where is more by chance you neglect it so it will be catastrophic

because you are doing the process very fast.

capital cost is very high a banbury cost several you know tens of you know 30 40 crores of rupees. So, that way it is cleaning is difficult so that is why I told you if you have two banbury you mix gel purpose rubber like SBR (styrene butadiene rubber) or butyl don't try to use butyl into the gel purpose because butyl and gel purpose rubber they do not go well so cleaning will be difficult. So, that is another disadvantage is I am not going into the details of it for the timing. So nonetheless you know internal mixer is a very great you know machines to do it once again what I did not touch upon is the rotor design part of it whether to go for 2 wing, 4 wing, 6 wing, and what type of design gives you whatever flow it happens in between the rotor and with that different rotor design how the distribution of the shear forces happen how do you do the heat balance how do you calculate the rheological properties but one thing although apparently those two geometries are different but same things, you want to practice in internal mixer what namely high intense mixing that is brute forces. Number two elsewhere you have low shear blending action and thirdly cutting and folding that your rotor design takes care of it, It's goes one way to one rotor through and through the second part it cuts it takes it to the other rotor.

So, automatically does the circulatory motion takes care of cutting and folding action. So, that way principally it is it does the same job what it is apparently doing in a two roll mixing. So, what I taught you today a more controlled and precise mixing techniques using internal mixer, essential parameters involve cooling systems although I did not talk about different types of dumping I mean after dumping you have to really dissipate the heat many times it can be either 10 ml set beneath the you know rotor. So, it is a two internal mixture combination or it can be a simply two roll mill to handle it handle the temperature or add some additional curatives there to finish that operation. But nonetheless from the commercial point of view as minimum is the number of passes it will be more cost effective again you not have to compromise in terms of quality if you do so it is going to be catastrophic.

So, this is all about mixing. So, I believe so you understood by now how these different ingredients are mixed together using different machines and giving a little bit of rheological sense of it. So, now we are all set to look into the next part of the processing which is nothing, but shaping operation we will start with the molding techniques in the next upcoming lectures of course, calendaring you know other parts also will be covered with that. Thank you very much. Thank you very much.