Rheology and Processing of Paints, Plastic and Elastomer based Composites

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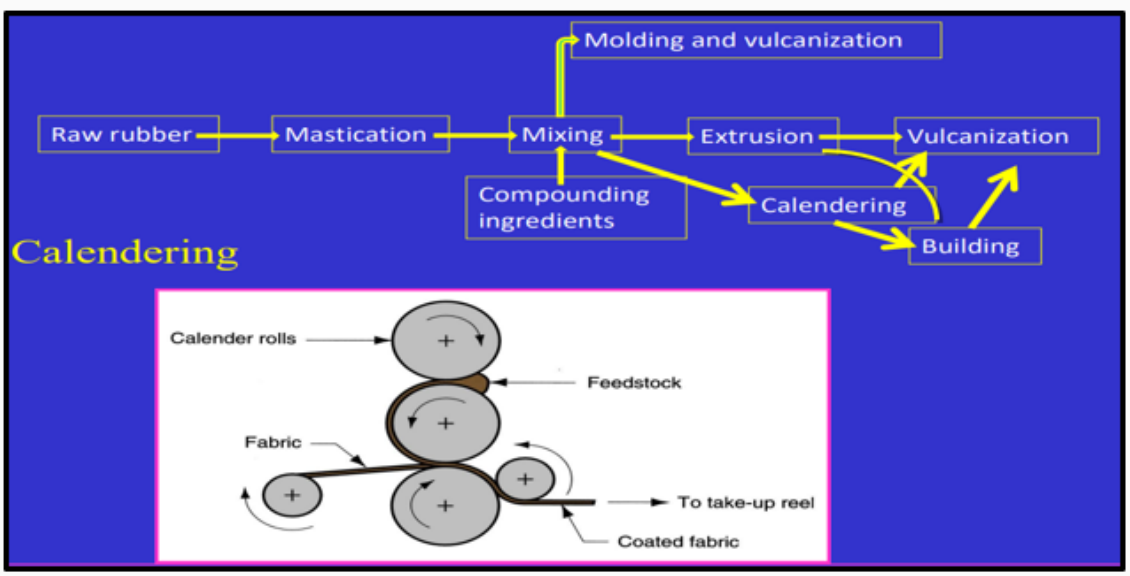
Lecture 38
Calendaring

Welcome to the NPTEL online certification courses on the rheology and processing of paints, plastics, and elastomer-based composites. And this is lecture number 7.2, we will try to see calendaring which is one of the major processing operation or shaping operation as far as rubber, and as you know, fabric pliers are constant. Ply means its a sandwich basically between the rubber and fabric. So in that we will covering we shall be covering the calendaring and its little link to the rheology although I will not go into the details later on we will take care of. Types of roll and roll configurations mechanical construction of calendars.

Heating and cooling system is very important because you need more precision rather in calendaring machine rather than the two roll machines I talked about ok. So basic geometry wise the calendar and two rolls are not much different only thing is that if you put another one roll it becomes a calendar three rolls combination becomes a calendar four roll combination becomes a calendar ok. Even a single roll two rolls can be a calendar actually ok. So ah, but you need to have a precision in terms of you know ah the nip nip has to be very consistent nip the total from the length wise width wise it should be very consistent.

It should have a precision in terms of you know ah temperature also across ok. So those are the some of the things are to be taken well care of additionally as compared to you know two roll mixing mill here. So ah we will talk about a bit depiction on this performance controls as well. So about the keywords again its all given I mean I am not going to go each an individuals, but more importantly some of the calendar defects like close fit defects blisters ok are are are very very important I mean little bit on the roll bending little bit on the you know roll cambering or crowning basically ok. So sometimes you have to make sure rolls are not very perpendicular they are crossed ok.



And sometimes its not very uniform thickness at the center it has to be little bit more thickness I mean I mean rather little less thickness will ultimately the nip will have in order to make take care of the you know calendaring ah calendar sinkage problem. So these are the some of the parts you must be ah must understand before you take care of the unit process. So calendaring could be defined as a process of converting a polymer material or compounds with or without a supporting fiber. It can be a rubber as such there is no support like no fabric that also can be made rubberized sitting can be done by the process of calendaring, but most often ah from the processing rubber processing manufacturing point of view it has to have a fabric. So you have a fabric that should be pretreated with the bonding agents and on top of that you have a rubber coat and depending on your process requirement it can be from a single side coat or it can be from the double sided ah coated because ah in as far as tire manufacturing is concerned it is from both the side the coated materials, but a bag earlier you might have seen ah not today's bag where it used to be rubberized bag inside the you can see the textile liners because it is a one sided coated ones ok.

So rubber compound plays very important role see if you have a low molecular weight polymer imagine ok and I trying to make a calendar sheets you may not be ultimately having a defect free ah calendar surface ok. So those are the some of the consideration you should have some optimized geological properties of the polymer or rubber or rubber compounds you have to consider. As far as process parameters are concerned role speed again the friction ratio sometimes the temperature role nip gap extent and rate of extension and viscoelastic properties as in the hole are important. So if I want to really one to one have a correlation between the calendaring and you know rheology all that I taught you so far. A simultaneous application of shear stress at elevated temperature results in deformation of the material that you understood by now.

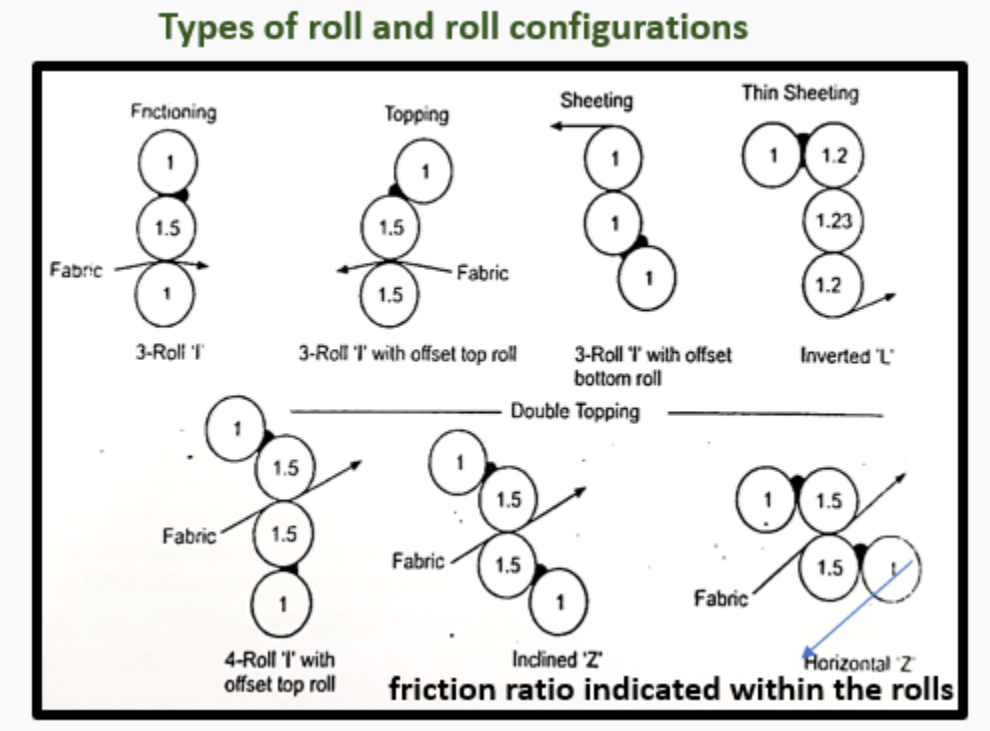
And the direction depends on the deformation of the material and manifests itself in several factors. An increase in thickness of the film after releases from the nip of the calendar and reduction of the width that is what is called calendar shrinkage of the calendar systems depend on the input rheology and temperature. So ultimately at the end like in extrusion you try to get rid of dice well reduce the dice well. You have to reduce really the second normal force difference I emphasize that time. Here also while calendaring I mean if it is a calendared finish products that you have to consider.

But suppose if you are trying to make a intermediate material which will be sandwiched ultimately it is a side wall construction. It may not be that important in terms of the surface precision and all. So that depends on the case to case the changes in line with the dice well as shrinkage phenomena associated a polymer due to the viscoelastic characteristics of it. So again to give you a quick recap where we are we talked about rubber in the initial its rheology we talked about. So we assume that we have finish all the steps recap the example of the train starting on a mastication incorporation dispersion, dispersion distribution and plasticization.

If you finished it you are having a optimum material one part of it go for molding that I already talked about that is why I put molding and vulcanization together. But when I am talking about later process like calendaring extrusion that I am going to talk about these are the shaping operation only we are not considering it at all the vulcanization ok. We have to make sure of the up to the point I have any fixture and then assemble build its called building. It can be a conveyor green belt building it can be green tag green means not vulcanized it is not looking green or or or anything else environmental different. I am just talking about just you make component by component one component say for example, side wall you made it by the process of calendaring top part of it trade you make it by the process of extrusion ok.

And other components also can be a combination of extrusion and you know ah calendaring and then you assemble into a pre shape that is what is the green shape and then finally, you try to vulcanize it that is going to be the story ok. Suppose if you are making a wire coated with the fabric after extrusion still green and then it has to go to the vulcanization ok. So, similar so in a calendared sheet if you want to make the first step is to make it a sheeting profile and then you you have to either go for a you know ah batch sort of a vulcanization or you have to go for a continuous vulcanization. Remember one thing if it is a continuous vulcanization whatever process it is associated pre shape process that line speed has to go along with your vulcanization tunnel if it is a hat hot hat curing system ok that you keep it in your mind. So, so far we are into the calendaring extrusion part I have not covered I am going to cover vulcanization I am

keeping it aside I am not going to give lot of light at this stage on vulcanization ok.



So, we are into calendaring now. So, what you have you have a feedstock from some of the nip of the calendar it is a thin roll calendar I shape because it looks like see I ok I type of geometrically also calendaring I will come there. So, you feed it here and then your your fabric is fed from here. So, from this part it is actually coated coated by calendaring process. So, you have a ply which is a sandwich between the rubber and you know fabric ok.

So, two process two unit process are important as far as fabric is concerned first is frictioning ok see friction is nothing, but your fabric is a mesh basically right. So, you have a interstitial position. So, if you just put a lamination like I am depicting here. So, rubber may not reach optimally cover the textile interfaces end of having air pockets and those will as you finally, you know you know build it and vulcanize it there will be further expansion of those air pockets and defects. So, what you are make the first unit unit process relatively less viscosity material called friction compounds.

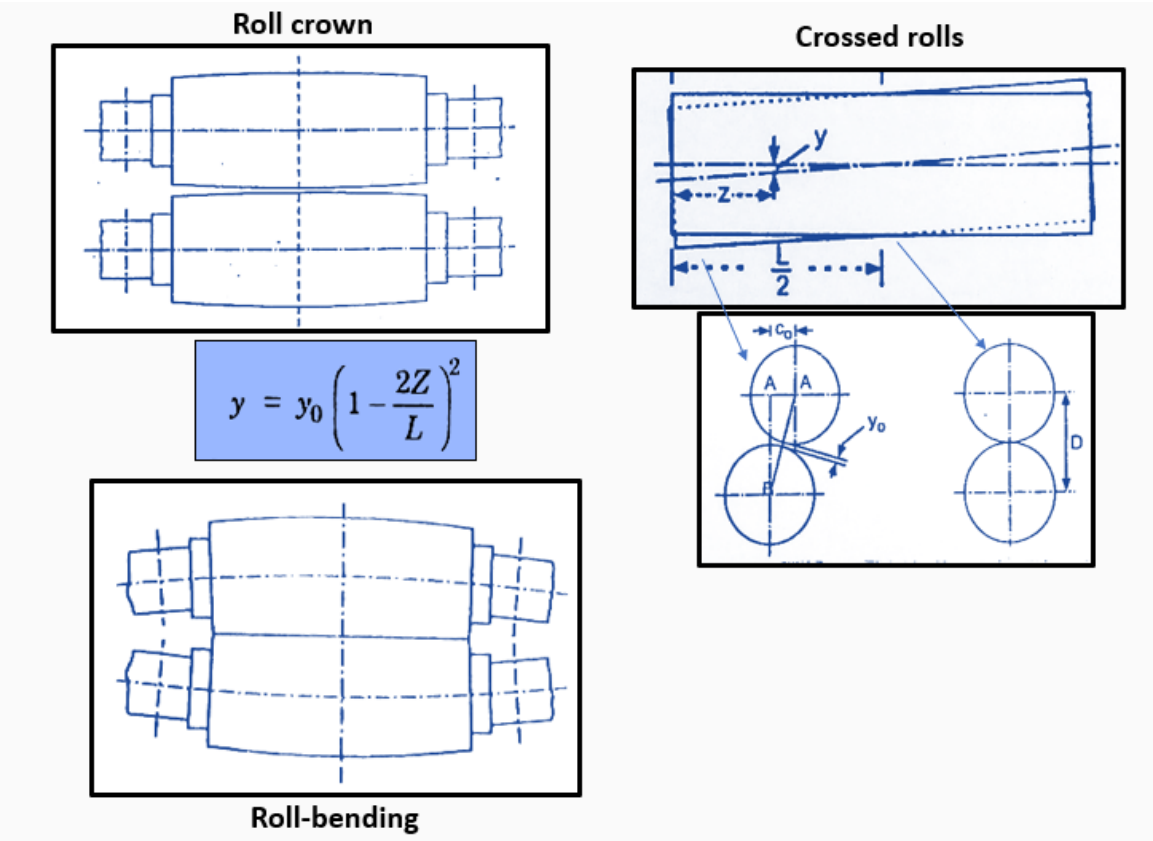
So, two rolls the fabric and calendar will rubber will move in a different speed ok naturally rubber has to move faster. And it will try to have a friction on the fabric it is called frictioning and that means, you make sure rubber already occupied the interstitial position. In the next stage you try to go for the sort of a lamination which is called coating basically ok on top of the fabric. So, that is how the the the plying is done the

plies are manufactured. So, as as far as geometries are concerned this is I am just depicting 3 roll and 4 roll because those are the calendars 2 roll is never called a calendar rather.

So, it is a I type it is a you know inverted I type ok and that is how you can foresee I mean and whether top is inverted or bottom is inverted. I mean this if you draw a line here is inversion here. So, you can say say kind of a l or inverted l type ok. So, other than that so, what is the difference between 3 roll and 4 roll generally 3 roll calendars are meant for coating a single surface ok. So, even if using 3 roll I mean 3 roll calendar you can coat it from both top and bottom, but you have to flip it one side you coat it say say for example, here the fabric runs here from the rubber comes one side top side then flip it and then try to coat it in other go another go.

So, it is 2 step process on the contrary if you have 4 roll calendar you have 1 nip 2 nip let the textile run in between. So, both side rubber will fed in and then it will be able to coat it from the both sides. So, once again it is a inverted l type just inverted l you can see the geometry ok. So, offset it is not inverted exactly little offset 45 degree angle it is offset this roll compared to this 3 rolls ok. So, now, it is a inclined s or inclined z or s type sometimes called and it is exactly z types ok.

Now, you can ask me the questions are why why should I go for different geometries. First of all if you are I type you have more vertical space. So, horizontally in the sub floor you have more space while in the z type or inclined type you have a gravity feed your feeding becomes easier. So, you have to make sure what is your factory design actually. So, depending on you have to pick choose either or the other, but obviously 4 roll calendars are costlier than that of the 3 roll calendars ok.



For a big manufacturing process there is no question of doing it in 2 goes rather in one sort you try to coat it from both sides that is how it is you know top and bottom coat. So, of course, depending on the requirement you you may have to have a some certain friction ratio then the middle point 1, 1.5 and meant for the speed of the rolls are depicted here. So, friction ratio is indicated within the roll I am not going into that details of it, but nonetheless you know frictioning operation if you want to perform you need to have a friction I mean differential speed between the rubber and the reason I already told you. So, one thing the first question arises in your mind what the rolls are made of these are made of chill cast iron and case hardened most often.

So, you can understand one thing for sure that this calendars are to be robust if there is a bending or deflection happens can deformities happen under the high pressure of course, rubber being a viscoelastic fluid although you have a most bearing so, design that the it will not allow to, but rubber also can undergo I mean cylinder I mean steel surface can also undergo sort of a deformation. So, it should not be first place get rusted second place it should not get deform. So, you need certain requirement on the as far as material is concerned of construction of the. So, it is bearing it is you know material of construction is matters. And second important thing what I am going to talk about as I mentioned it to you the nip plays very very important role unless you have a very very precision over the nip then there will be one side it will be thicker other side it will be

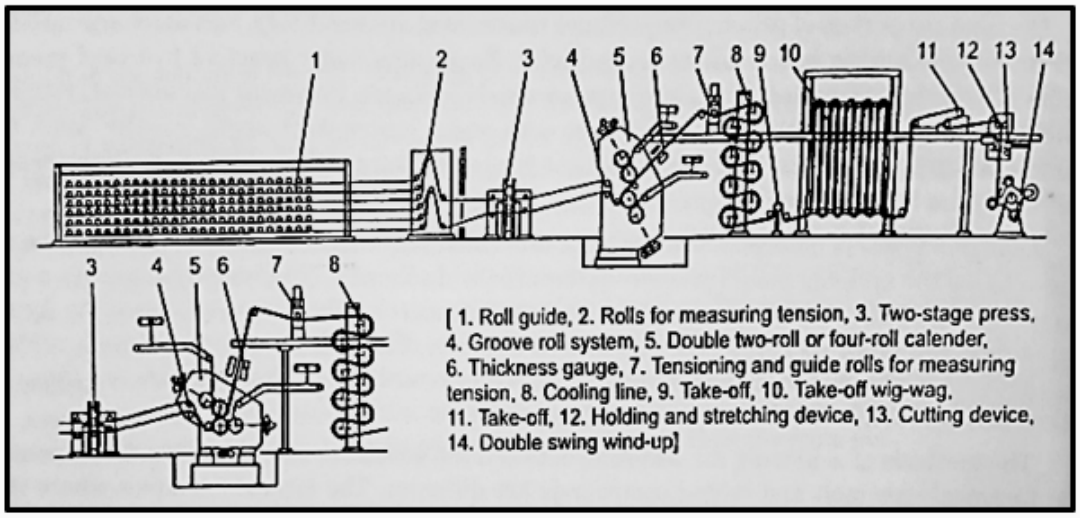
thinner.

So, in order to get rid of those problems even the calendar shrinkage problems one of the process is called roll crowning as I mentioned it you instead of having this sort of a nip this is one cylinder this is another cylinder another roll one another roll. So, it should be some sort of a extra thickness is this thickness is that taken care of that. So, that calendar when shrinks then will be no question of you know calendar shrinkage basically no question of thickening happens otherwise it will be thicker at the center thinner at the two sides this these two places this side side places once you get a calendar shrink. So, that is one thing, but then again the roll crowning will be different from material to material because it is viscosity elastic component of the fluid will be different.

So, you have one machine. So, you cannot really do it. So, in order to get rid of that there is a process called roll crossing just crossing the roll you can take care of that shrinkage component and crowning part of it. So, those two things are written I mean the roll crowning is written here and roll crossing is written here and roll bending is also sometimes being done. So, roll crown is depicted here giving a more thickness of the roll at the center position compared to the side and then roll crossing certain angles you keep those two this offset and roll bending is also in the axis itself you have a bend basically because you have a tremendous separation force you can as you can understand. So, actually so you can calculate the deep clearance for a cross rolls with that angle of you know distortion you can actually calculate geometrically y equals to y naught 1 minus 2 z by L.

So, L is the length of the roll by the way also you can calculate I am not going into the details you can calculate the pressure at different points once calendaring. So, you may be wondering one thing from the very first principle the pressure build up is more in the just like on the nip actually it is not happened. So, it happens little bit off from that place that is the maximum pressure it accounts for. So, I am not going into that details for the time being, but obviously as I mentioned HU heat transfer also plays significant role in determining the performance of a calendar. As I said code rolls are small laboratory rolls otherwise it is a peripheral drilled typically 50 millimeter from the surface the water lines or convection liquid line will be there.

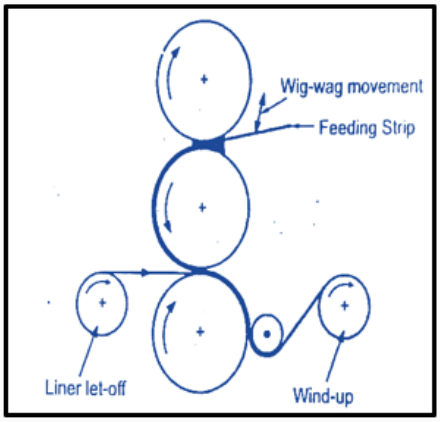
Calender line

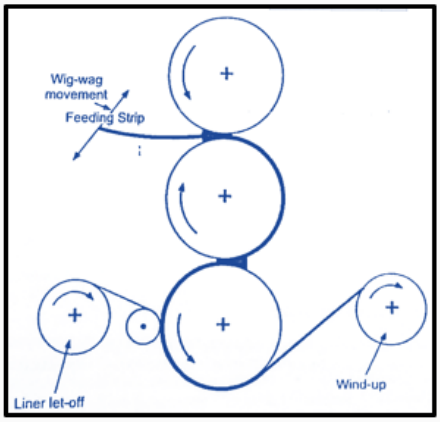


So, if it is made think about very very you know shallow the length. So, it will be prone to deformation. So, you have to really calculate how much actually separation force it is going and that should not exceed the yield strength or of the material otherwise your roll surface itself will be deformed. So, it is bending stiffness plays very important role in that is sense. So, again it is a chill cast case hardened material it has either peripheral drilled or centrally cored depending on type of rollers you are using whether laboratory one or commercial one and what is the you know working distance you want and that depends on.

CALENDERING PROCESSES

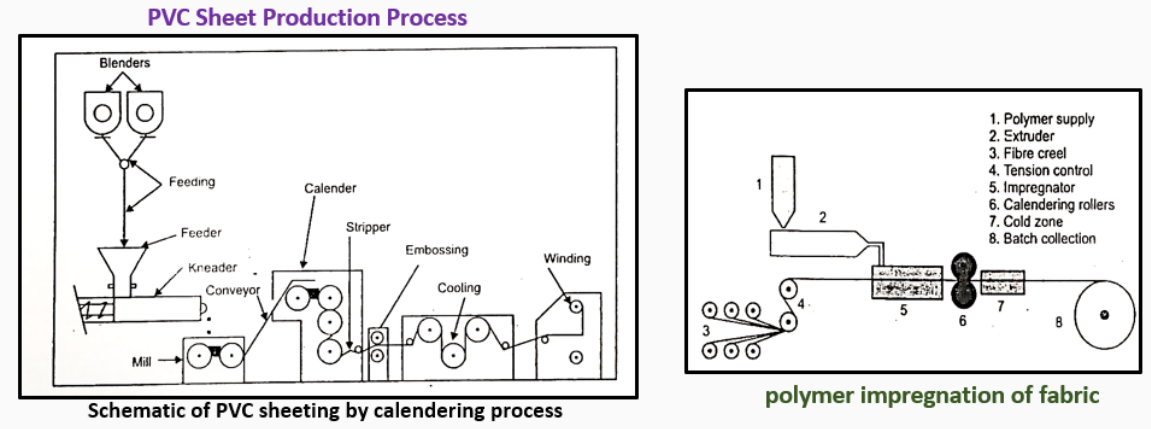
Threading of calender for sheeting (single nip). **Threading of calender for sheeting (Double nip).**





So, for example, in conveyor industries I mean textile conveyors conveyor building construction you have to have a some either cut edge construction or molded edge construction and depending on the specification you need to have that much of thickness

of the I mean width of the rolls. Let us take an example of PVC. PVC is also very very much used as I mentioned it to you in our childhood days we have seen the PVC bags those are made by calendaring process. So, a temperature above 200 degree centigrade although rubbers for obvious reasons you cannot do that high temperature because you have curative in that you do not want it to get cured during the calendaring process. So, that is what as per as PVC is concerned it is a thermoplastic you do not have to bother about that only thing is that you have to bother about the stability of PVC, but while in rubber case you have to take care I mean take it into consideration it is you know scorching problem I mean curing part of it.

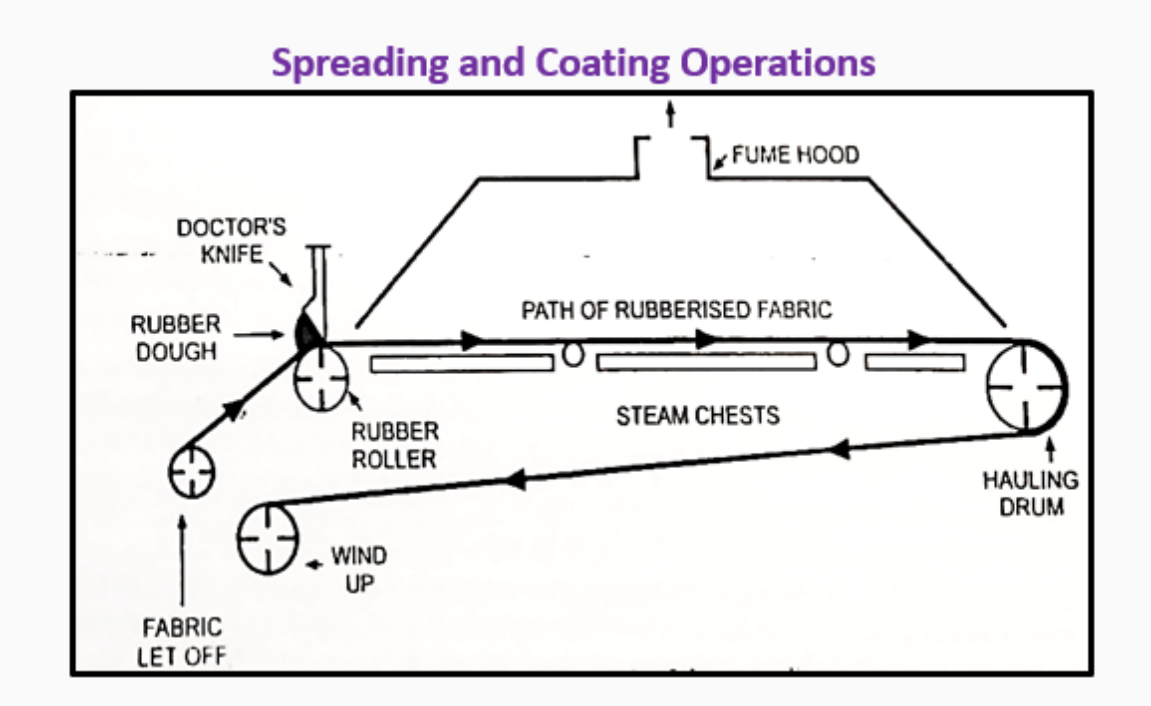


So, line contains a number of let us try to examine one line from the industry point of view how it looks calendar line. The line contains a number of auxiliary units I mean including the feed as I mentioned sometimes the feed has to be weak work rather than a straight feed if you have a straight feed what will happen guess there will be additional tension important while the process is running in the process that will happen. So, that also the accumulator or weak work sort of a designs necessary what is feeding. So, feed can be of different type I mean that also depends remember one thing before I forget calendaring has it is own limitation you cannot really calendar very thick article say typically 1 1 2 millimeter beyond that if you go there will be some sort of a blister formation and even if you go for a very small thickness 0.1 millimeter or low there will be a problem your role may bend with that pressure it generates.

So, then you can ask me the question sir how do I make a thicker calendar sheets is done by applying techniques or else you have to bank on extrusion basically the roller head dies basically. So, I am not going into that details right now, but let us try to examine what is there you have a fabric. So, there is a tensioning unit cooling line take off wind off that unit has to be associated other than your geometrically what I showed you 3 or 4 roll combination. However, it can be vertical it can be offsets it can be z type depending on type of feed system depending on the space constraint in your you know

manufacturing site it all depends on that. So, those who are familiar with it is a daily affair for them those who are attending this course working in the industry looking seeing calendaring and extrusion every day ok, but those who for them is the first time the calendar is go through the step by step both from 1 to 14 every single unit is depicted very clearly here.

See material used in the calendaring at 2 types grossly the polymeric types like base polymer and different ingredients as simple as that as I elaborated you ok. And then second one is the textile like it can be in the form of a fabric it can be yarn it can be cot say say for example, if you have a fabric you have to do 2 steps one is frictioning another one is topping it is called coating or topping whatever way you can say it is normally called topping ok. And then if it is a cot all together different ball game in fact, and indeed if you have a fabric ok this fabric should be done with certain sort of a treatment as I mentioned you already if it is a cotton does not need any pre treatment if it is a you know viscous or rayon you it need some smile at treatment if it is nylon more you know extensive treatment ok. If it is polyester even further 2 step isocyanate followed by rfl or you know vp latex sort of a coating techniques needed. So, calendaring process mainly as I mentioned seating, seating means no fabric pure polymer you are trying to take it in the form of a continuous seat.

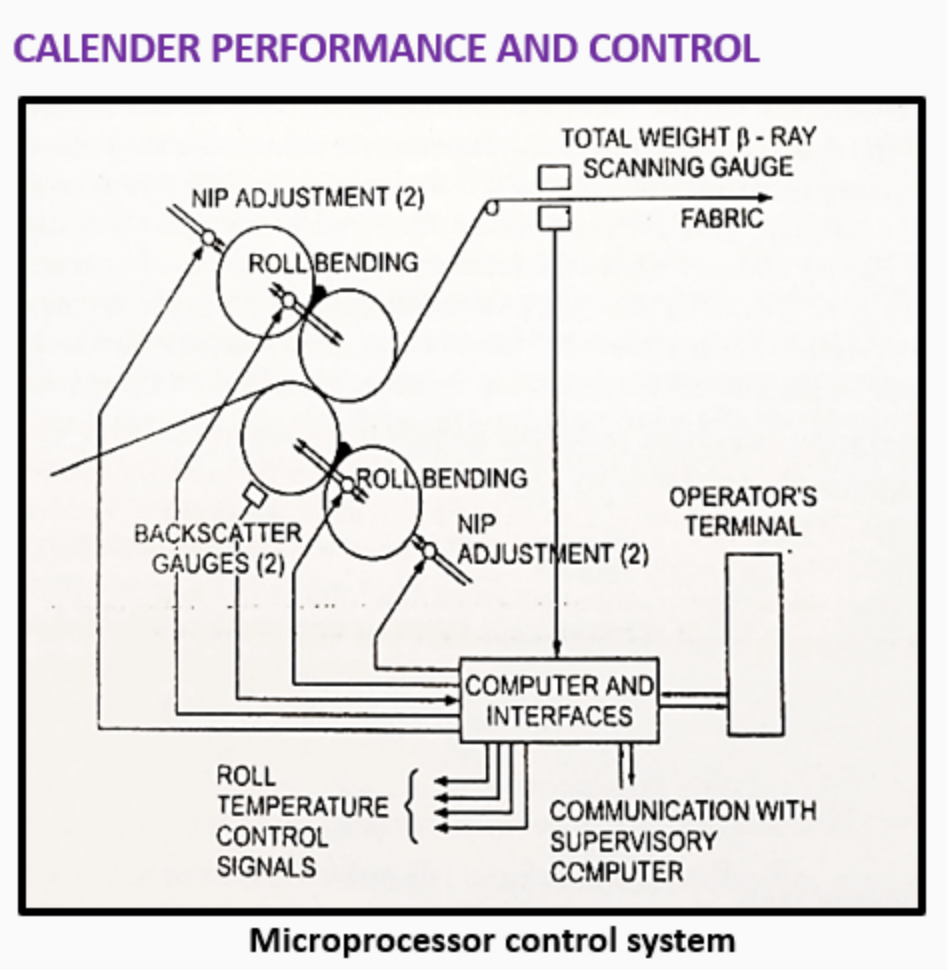


A second is a frictioning as I mentioned make sure the adhesives bind there should be a fabric and rubber bonding ultimately any product whatever product otherwise it will be a catastrophic failure premature failure. And the third one important unit process is fabric

coating which I already named you as topping it can be from both sides or single side again. So, profile calendaring in addition to this the calendars are used in combination with other processes ok. So, an extrusion calendaring of PET to produce a biaxially oriented film for audio video cassettes that is another example ok.

So, it is a combination of 2 processes remember. Second is dip calendar process. So, dipping and calendaring 2 different techniques are being utilized it is done by PVC covered conveyors ok. So, you can see here the same 3 role calendars ok. So, where your ultimate feed is from where it depends it can be a single nip and it can be a double nip. So, double nips you are trying to utilize both the nips along with the fabric and the polymer.

So, this is how you can you can you can practice ok whether to use a single nip otherwise you would use a nip as a feed of rubber and the second nip actually where you are actually doing the coating operation or topping operation or frictioning operation or or or other way round. So, obviously, the fabric you can see it from here fabric liner how it goes. So, wigwac conveyor head I already talked about it oscillates basically in order to get rid of the tension. Single nip arrangement for producing one sided liner supported and interleaving material such as fabric which prevents the compounds sticking to itself. And if a more precise control of the gauge means the thickness across the width ok.



The number of blisters it may so happen 2 things if you have certain sort of a you know roughness generated ok. So, like a close feed or surface undulation you can pretty much get rid of or or rectify it by increasing the temperature while calendaring. But if you increase the temperature there is another side of the story there should would be a blisters. So, what it is being done once it is calendared it takes between the a liner a polyester liners and let it roll for sometimes and that those blisters so form will be dissipating. So, that is how all the close feed close feed is nothing, but a low temperature it happened it appears like a patches of defects on the surface.

And the reason is that you are obviously, polymer flow was not perfect. So, temperature rise will try to increase reduce the viscosity of the system and therefore, those you know patches will will be disappearing, but at the same time at higher temperature be disturbed will come. So, it is a process called breathing that is being always done basically in the poly in in between the polyester liner.

And this is the range of thickness 0.1 to 1.5 otherwise higher you go you have to go for you know applying techniques you have to do separate separate calendaring and then

apply together. So, obviously, tack property it is important role while compacting different layers you have to make sure there is no air entrapment there. So, those are the criteria decides the quality of the fabric quality of the calendar sheets you are going to get. So, without going into much details of the you know process control precise process control how you rectify, but what my intention was to give you a first hand idea about the calendaring process why you do calendaring process. And although I really have not shown you actually a flow through a it is very similar to what I showed you a in a two roll mills actually.

The flow is quite quite similar, but additional consideration is the temperature uniformity which plays very important role and of course, the gauge thickness. So, in the in the calendars actually beta gauge sort of a arrays of gauges are there in every point it takes care of the thickness of it. So, thickness uniformity also is very major major challenge in calendaring process. See this is the PVC sheet production process ok it is a pictorially depicted raw material like PVC with plasticizer, plasticizer reduces the viscosity of course, so it should be optimally sharpened. And then the the blend is so is fed into the fluxing machine in need of maintain a high temperature that is how your dough is prepared.

Then that dough has to be calendared onto the surface of the textiles is as simple as that. It is a similar process which I depicted nothing nothing very very new to you should be. So, polymer impregnated I mean the fabric some friction ratio is also mentioned reason I told you and that is how from feed to wind up unit you can see it from here from this depiction I am not going into that details each and everything. But prior to calendaring machine was obtained there is to be a process called spreading ok to make a rubberized fabric or polymerized polymer coated fabrics. So, it is none other than that what it is to be done polymer was made in the form of solution.

And by a doctor blades sort of a coating the fabric goes through that solution and the doctor's blade sticks into account its thickness component of it. And then it has to go through a fume hood where it the solvent has to be evaporated. And this is spreading or skimming it is to be called ok and you get a rubberized fabric it is a very old fashion technique. Let me tell you one thing because it has a solvent because it has a fume even though you put it in fume mode this particular component of rubber industries at the earlier time used to be most hazardous.

The all the fire events used to happen from this unit. So, good that it is being grossly replaced by no solvent hazard calendaring technique ok. So, earlier factories you go for a particularly bag making industries bag manufacturing industries. So, industries people used to do this spreading operation. So, it is almost almost not existing today. As I

mentioned calendaring defects includes variable gauge thickness blisters holes nibs fish eyes fish eyes happens if the polymer molecular weight is quite quite low.

So, you have to really reject that go for a higher molecular weight side because remember one thing it has to have a some strength ok. And then fabric crushing pill coating friction picking off cold checks close feet I told talked about. So, without going into the details of its incidences that happens the defect incidences. And like rather than going for troubleshoot at this stage let us try to understand this very fundamentally because this course is a once again designed for the basic learner. So, what our intention will be there so far what rheology I taught you you should be able to take it into consideration to and the industries as far as industries is concerned you rather use your basic conception that I taught you how you have a best balance between the viscous and elastic component that is that place in majorly major role and you know how it depends on different parameters.

So, accordingly take your call and try to rectify your problems at your end that is what will be my suggestion. So, quickly to look it at there are certain being a troubleshooter I mean I mean to to you know address the troubles solve it. So, the defects can originate from the material point of view it can arise from the machine parameters it can affect from the temperature related defects I am keeping aside the operator related defects for the time being and those are glossed these are the reasons why it happens. So, you can see that if you have a low molecular weight polymer forms a small raised lumps called nip or fish ice I told you already. So, you have to really go back have a quality check on your raw material and rectify.

So, some of the variables like variable pressure crushing distortion roll drowning you look it into that roll crossing whether you made it at right angle or not. So, make sure those things are happen even the friction pick up defects own out gears that is a basic problem I mean in a factory you must have a very regular maintenance because it is all that deals with a very heavy pressure of separation. We are trying to deal it with a very viscous material forcing it to a narrow nip and try to have a certain fly type of a construction. So, always keep it in mind. So, this is the calendar process control system although today's four roll calendars are very automatic it gives you alarm in terms of process and process control systems, but otherwise you should have a processing record one batch to the other continuous monitoring in line and off line process control that will give you a very very you know ISO 9000 to 9001, 902 or 6 sigma diver by manufacturing process remember.

So, that much of precision is needed. So, precision, uniformity, reduction in material wastage, mixing time reduction, scrap reduction and increase of the production. So, that

is how you you take care of the whole whole game of that. So, a large precision calendar operation it is important to determine the process capability of a calendar line and fix the operating window for satisfactory performance. So, calendar performance depends on number of variables like as I mentioned it to you let us check it for the temperature of the rolls that is very very important feed stock temperature rolling bank volume rolling bank remember this is the rolling bank here depicted with the rubber number of roll nips roll speed and speed ratios stock rheological properties and wind up tension even the accumulator and that you know feed also plays very very important role. So, I will not go further into that some of the you know particularly this reference you can see this is also quite good it is it also includes the calendaring process, but there are other references the lecture has been taken many other references.

To sum up I have given you a basic introduction to calendaring again in a nutshell two three things one is a purely sitting operation second thing is a frictioning operation and third one is actually is a topping or coating operation earlier it used to be a spreading technique that is by and large replace by calendaring techniques. There are certain way you can take care of calendaring calendar shrinkage part of it because of the viscoelasticity of the fluid elastic dominance of the fluid like say roll crowding roll bending and roll crossing. And of course, so certain defects processing defects including close feed surface on regulation also the blistering effects you can get rid of there are certain limitation of calendaring in terms of thickness window point one to one point five or two max that is the thickness you can consider otherwise if you have to go for higher thickness you have to go for time techniques. With that that gives you certain ideas elementary idea about calendaring will come up in the For the next upcoming lectures on extrusion injection modeling, stay tuned. Thank you.