Polymers Processing and Recycling Techniques
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Lecture – 70
PolCoPUS: Polymer Processing III

Hello, welcome to the course on polymers. We start another week of lectures and we are continuing with our discussions related to polymer processing and recycling techniques and these processing techniques are extremely important in terms of determining the overall performance and we started this overall discussion in the third lecture itself where we talked about process structure properties.

And so, all these interrelations in case of macromolecular polymeric systems is very fascinating. Processing determines properties, properties determine processing, processing determines structure, structure determines processing and of course structure and properties are related to each other. So, we will continue discussing some aspects related to polymer processing operations by focusing on the applications and the applied aspects.

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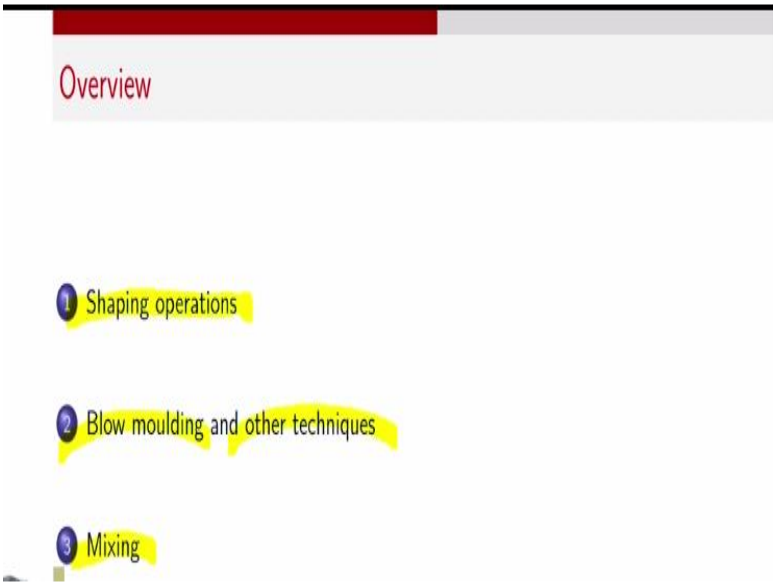

We look at what are the broad shaping operations which are used, specifically we look at blow molding as a processing operation because it is used quite commonly for polymers and there are several other techniques also which are useful and in all of this mixing is an important component and we will spend some time thinking about how is mixing different in case of polymeric material as opposed to when we mix sugar in water for making juice or we mix it in milk for making tea or coffee.

How is that mixing different compared to a system where there are macromolecules involved, where rheological response is quite different and also the segmental mobility is there, but given that macromolecule is a very large molecule the diffusion coefficient of macromolecule is much lower than that of small molecule. So, all of this we will review in this lecture.

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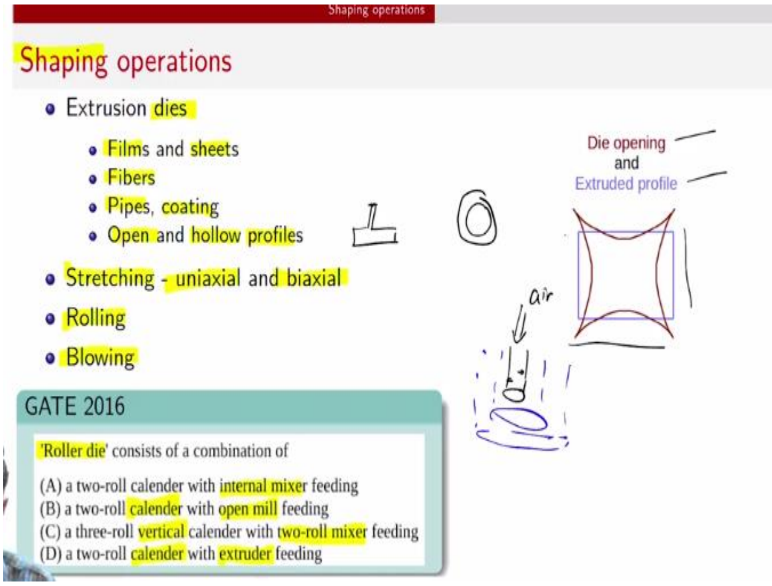

So, the shaping operations are of different class. We have basically dies through which a polymer melt or a polymeric resin plus fiber mixture is extruded and this could be to make films or sheets. It could be to make pipes or it could be to do wire coating or to make fibers and it could also be in case of let us say pultrusion or in case of making other objects like C-sections or I-beams. Again, we can have either open profiles or hollow profiles.

So for example we can have an I beam preparation in which case the cross section area will look like this and so the extrusion die will have to have a T shape. On the other hand, we can have a hollow profile also in which case we will have the opening which is commensurate with this shape required. However, the die opening and whatever final extrude profile are very different and this is because of couple of reasons.

One, macromolecules are being forced to go through the narrow opening and we are forcing the segmental stretching and other operations at macromolecular level and as soon as it comes down extruded again the macromolecular recovery is there in terms of conformations changing again back. Also, there is surface tension of macromolecule and surrounding air and so based on this what is the shape of the extruded profile can be very different.

So in the end let us say if you want this rectangular kind of profile, then the die opening can be much more complicated and this is something which is done based on understanding that a polymer engineer has in terms of how does the extruded shape depend on the die opening and this is generally an empirical, semi-empirical and some fundamental insights which are combined to get this operation.

Once the extruded part is there, we have to do stretching. For example, we saw biaxially oriented polypropylene films or we could also have uniaxial stretching to get a fiber of a definite properties. We saw that ultra-high molecular weight polyethylene stretching is done to such extent draw ratios are extremely high so that chain orientation is extremely high, so such stretching is involved. We may also use rolling to do the shaping.

In fact, if you take up material on a roller and if you rotate one roller faster than the other, then again stretching happens and of course we could also have blowing and in case of a bottle making blowing is used, in case of film making blowing is used where from inside we blow the material. So that if I let say extrude a pipe, so I will get a pipe being extruded and in this if I blow air, what happens is this air will try to push and in effect this film will start blowing and that is the process of blowing.

And that again will lead to stretching and shaping operations, and of course the thickness will depend on how much it is blown because it is the same amount of material which is being now blown to a very large extent and just to highlight various set of shaping operations and how different industries use different nomenclature, roller die is a term which is used generally in rubber processing.

And you can try to look through and analyze what is it a combination of, is there an internal mixer involved, is there an open mill, is it a calendar, is there a vertical calendar with a mixer, what is it or whether it is just an extruder feeding with a two-roll calendar? So try doing some search and you can I am sure arrive at the answer.

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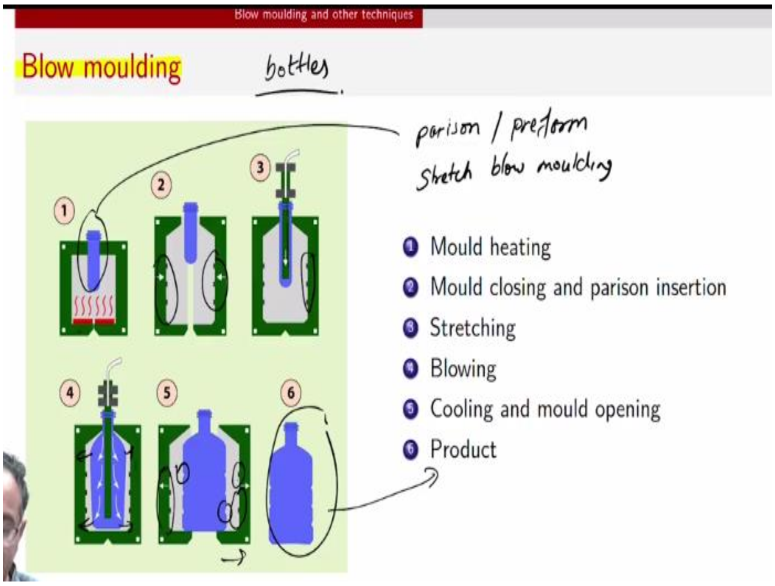

Let us look at one operation in again little more detail. This is blow moulding which is used for making bottles and the bottle will have very different features on its surface and those are basically put on the mould also. So the mold decides whatever is the outer shape of the bottle and how this bottle is made is you start with a what is called either a parison or a preform. So there are two ways in which this blow moulding operations is done.

Sometime you extrude this, at the same time blowing can happen and then you can make the part or you can injection mould this and then just put it here and then do the blow molding operation. So for example here this has been injection molded and now what you do is you close the mould and heating is done so that this blue polymeric material can deform and then what you do is you inject a rod, so this is called stretch blow moulding.

So you stretch so that polymer molecules get oriented. You must have noticed that some bottles are extremely thin and still they can withstand the amount of water filling that happens and the load that is supposed to carry and partly this is because the orientation has been manipulated by doing stretching and through these reinforcements, so with least amount of material you can have requisite performance in terms of holding the water and not breaking.

So stretching or stretch blow moulding involves stretching the polymeric material initially so that molecules get oriented along the direction and then blowing. So the fourth stage is where now the gases are blown into the material and since mould is closed what happens is this material will go and then conform to the mould surface and once the conformation happens then you can immediately start cooling and or stop heating and then separate the mould and you can see that these parts will be based on whatever is the mould features and then you can get the product and all of this process can happen very quickly.

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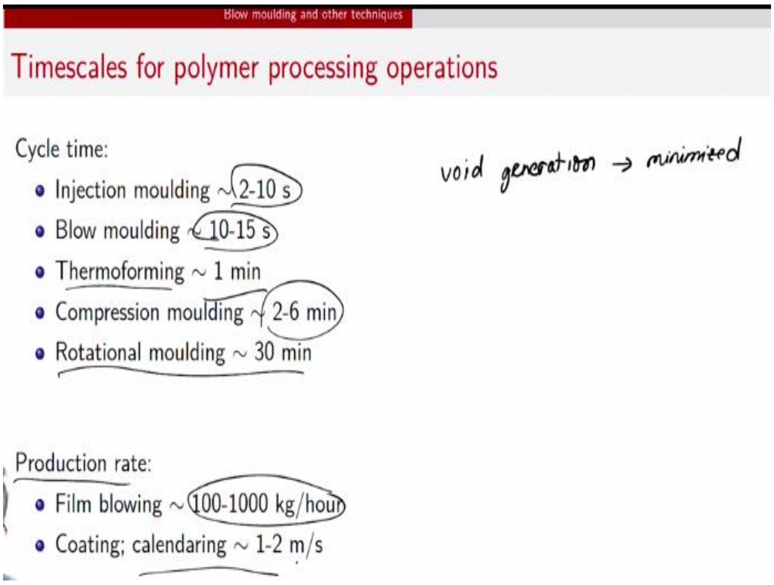

And just to give you how quick or slow the process is injection moulded cycle time is less than 10 seconds while blow moulding is also not very slow 10 to 15 seconds one can get a bottle out. Now you can see why there are so many different plastic bottle products out there compared to glass or ceramic container making these are extremely inexpensive operations because you can achieve volumes very quickly, very large amounts of bottles can be manufactured in very short amount of time.

Thermoforming which is also a quicker technique where the shapes are largely flat or slightly curved and it is like a stamping operation which is used in melt and so thermoforming the shaping is done between two platens and therefore the shape cannot be very complex, but again it takes just about a minute to complete the operation. Compression moulding on the other hand can have more complex operation but it takes more amount of time and many of these cases there are finer features.

For example, whenever we are doing these operations it is possible that gases or air can get entrapped, which will lead to voids. So in all of these cases, we will have to manipulate the pressurization, closing, opening in such a way to minimize entrapment of voids or the void generation. So void generation is a very important defect during polymer processing and this needs to be minimized. In compression molding for example, this can be done sometimes by doing what is called breathing.

So we can close the compression mould, then open it little bit and again close it to allow the gases or voids which are there to escape and so that is why it is called a breathing operation. We hope that the polymer will exhale the voids out. On the other hand, the tanks which are made using polyethylene quite often, water storage tanks that takes about 30 minutes. So through rotational molding, basically the thickness of the tank is made.

And these are quite thick tanks as opposed to the bottles or other thinner blow moulding bottles or blowing thin films, rotational moulded tanks are quite thick. These are supposed to hold thousands and thousands liter of water or other substances. In the case of continuous production units, you can see the mind-boggling amount of material that can be produced, in 1 hour we can make 1 ton of film and remember these are very thin films.

So this is an extremely large amount of polymeric films that can be made and therefore you should not be surprised that why these films are so ubiquitous and as polymer scientists and engineers it is now our responsibility to figure out sustainable ways of doing this. Coating calendaring can also be reasonably rapid where in a second we can process couple of meters of material.

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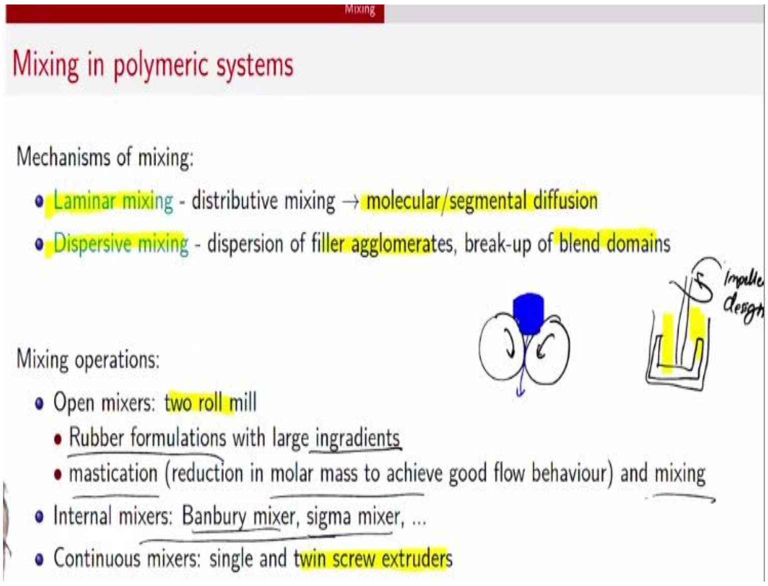

So in all of this, mixing is also equally important and mechanisms of mixing in case of polymers are quite different compared to mixing in let us say oil or water or air and things like that and that is because of the presence of turbulence. Because in case of polymers, the viscosity is extremely high turbulence is not observed and because turbulence implies that you know there are small eddies getting formed broken and there are lots of fluctuations in velocity and pressure at each and every point.

Mixing is actually quite fast and once these eddies get broken down to very small level there can be quickly molecular mixing, which is based on diffusion, but in case of polymer there is only laminar flow possible, which means one sheet of polymer moves, another sheet of polymer moves next to it and these two sheets may be moving at slightly different rates. So, mixing can only happen predominantly because of molecular and segmental motions.

So laminar mixing some amount of mixing happens, but eventually the rate determining step is molecular segmental diffusion. Of course, if we have some fillers or if we have blend domains, then we can also have a dispersive mixing where the agglomerates can get broken and then they can come together and so on or the blend domains can get broken. So, there is a distribution or dispersion of these fillers and domains through which again mixing can happen.

Generally, these mixing operations given that macromolecular mixing is very important in the end to get the final performance are done using several different types of operations. If we have basically roles as part of mixing, so we can pass the material through a set of rollers. So, there is a narrow opening through which we have the polymeric material and then we can force it by having these two rollers rotate and then we get the material out because now we are forcing it through the narrow opening.

And we are shearing the material and mixing will also happen, but again this will be laminar mixing and dispersive mixing because latex are mixed this way it is a multi-phase system. So therefore, particles can come together, particles can separate and so it will have a combination of laminar and dispersive mixing. So rubber formulations for example are processed this way because there are large number of ingredients which have to be mixed.

We can also use this to achieve a good molar mass because chain cessation and other processes can happen because of high rates of shear which are generated in such processes. So we have both mixing as well as mastication. We have of course internal mixer in which case we have a vessel in which a specific impeller or a blade is put and then this is rotated and again because of very high viscosity of polymeric materials, the mixer and the blades are very different design compared to mixing in case of low viscosity fluids.

So we have something called a sigma mixer and a Banbury mixer and crucial aspect in each of these is to have this impeller design. It is very possible because of very high viscosity that when we are doing this impelling action or stirring action, lot of material does not get stirred at all. So you have to have an impeller design which ensures that everywhere mixing happens. At the same time, this cannot be done very fast because the viscosities are extremely high.

Also in case of polymeric materials, viscous dissipation will lead to lot of heat generation and so very careful mixing rates will have to be used to avoid heating on one hand and to ensure good mixing on the other hand and we also have extruders and especially twin screw extruders which are examples of continuous mixers because internal mixers will happen to be batch. You add polymer in this and then wait for it to mix.

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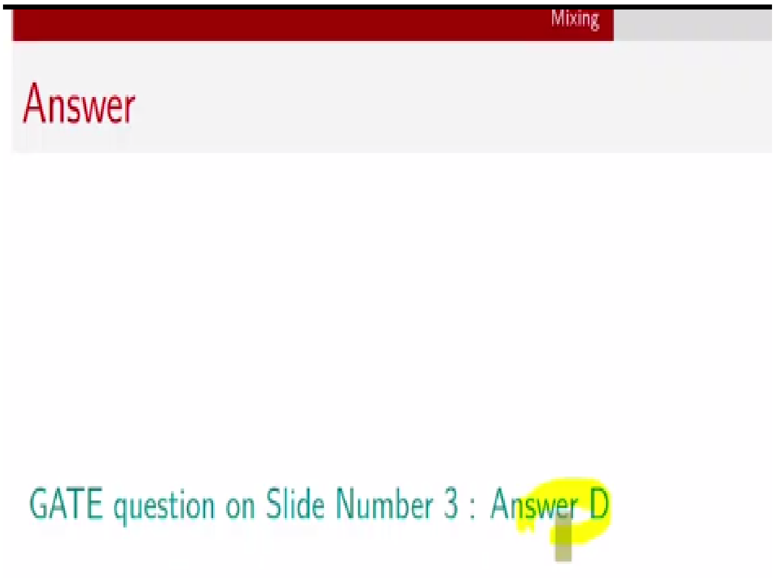

So with this, we will come to close the lecture and the answer I am sure you can get based on reading related to what are the different operations that are used in rubber processing. Thank you.