Thermal Processing of Foods
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Lecture No. 23
Importance and Applications of Extrusion Technology in Food Processing

Good morning everyone. So today we are going to discuss about importance and applications of extrusion technology in food processing. So last classes we have seen about the thermal processing equipment. So one is the various heat exchangers used in the industry and after that drying process, so where your heat transfer as well as mass transfer as involved as a as a mechanism of processing. So this week, we are going to discuss about the importance and applications of extrusion technology in food processing, so though the course is all about thermal processing of food. So we are also seeing what are all the other process which are included in the thermal processing.

For example, extrusion technology if you see so there is a heat transfer mechanism, mass transfer mechanism and the pressure changes there, shear changes there. So, altogether along with main theme of the course, which is nothing but a thermal processing. So in this lecture, we are going to see what is extrusion and what are all the equipments used for extrusion and the physical, chemical effects which happens during extrusion on the food and also we see 2 or 3 examples how so how the food material is made using extrusion technology.

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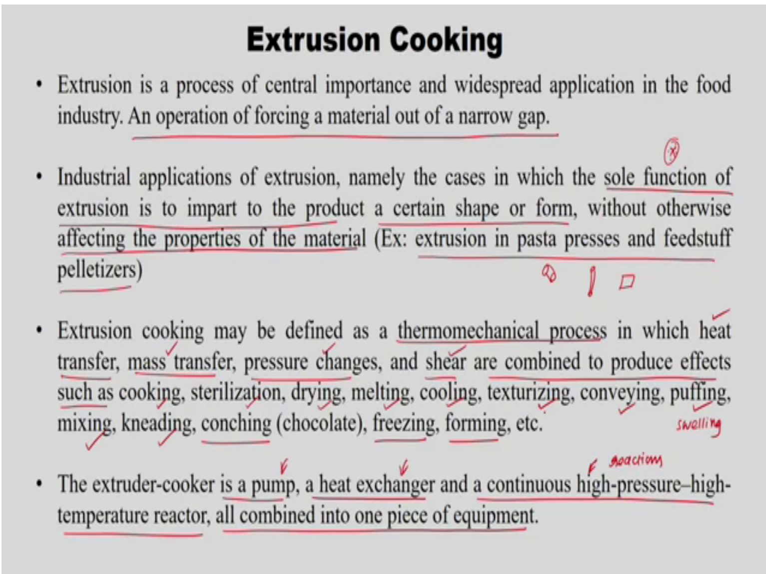

So the first is the definition of extrusion cooking so in the layman language we can say this is an operation of force in the material out of a narrow gap. So this has got widespread application in the food industry. So it is nothing but a forcing a material in a narrow gap. So the industrial applications of extrusion, so how to define the term extrusion in industrial point of view which is just nothing but a sole function of extrusion is to impart to the product a certain shape or form. So this is where the extrusion technology is being applied in industries without otherwise affecting the properties of the material without changing the property of the material so the product will be imported with certain shape and form. So that process is nothing but a extrusion, this is the proper definition in industrial terms.

So example is extrusion in pasta presses and feedstuff pelletizers. So pasta has got if you see kind of this shape or sometime the long shape also. So these kind of shapes are sometimes the pellets, pellet form also with shape and size we want so that also can be done using extrusion technology, industrially extrusion means giving certain shape or form to the food material. So extrusion cooking may be defined as a thermo mechanical process. It is not only thermal processing, it is a thermo mechanical process in which heat transfer, mass transfer, pressure changes and shear are combined to produce effects such as so the mechanism wise heat transfer is supplied, mass transfer is applied, pressure changes are applied, shear is applied.

So all these are together applied on the food material to produce the effects such as cooking, by now you know the sterilization, drying, melting, cooling, texturizing, texturizing in the sense, giving a proper texture or desirable texture to the food material then conveying, puffing, puffing is nothing but a swelling, mixing, kneading, kneading is nothing but a dough like structure and conching, conching is nothing but it is a particular word applied in the chocolate. So the mixing of the coco powder and ingredients of sugar, material, coco powder, the mixing is nothing but conching and freezing and forming.

So all these operations are simultaneously applied in the extruder. So one or two applications, maybe not needed for the particular process, but these processes are individually or combinely or simultaneously applied in the extrusion processing. So that means so lot of operations we can do together in a single equipment. So which imports the mechanism of heat transfer, mass transfer, pressure changes as well as shear.

The extruder cooker is a pump which is responsible for pressure changes your heat exchanger, which is responsible for heat transfer and a continuous high pressure, high temperature reactor so here, your some of the reactions may happen, for example protein denaturation. So a continuous high pressure, high temperature reactor all combined into one piece of equipment. So extrusion is nothing but forcing any material in the narrow gap, industrially it is nothing but a giving particular shape or form to the food material and lot many processes are combined together or maybe applied together or individually to process the food material in extrusion cooking and extruder is nothing but a pump heat exchanger as well as a continuous high pressure and high temperature reactor in one piece of equipment.

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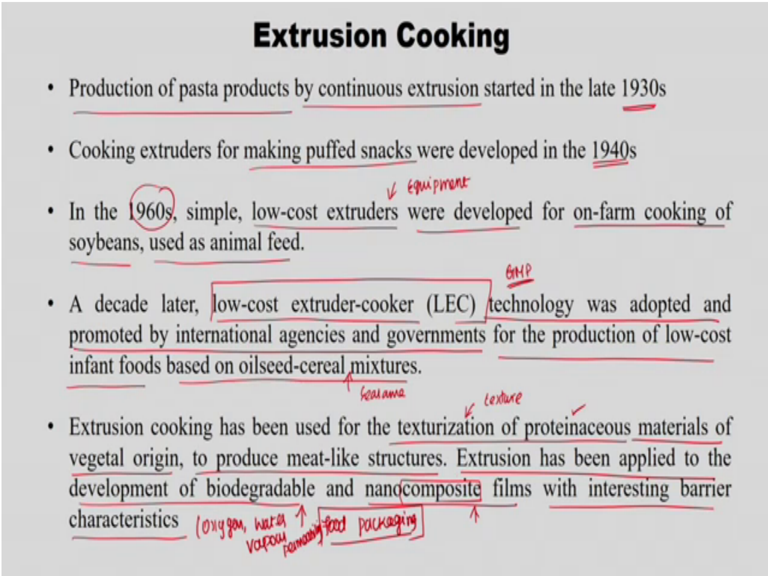

Then extrusion cooking so little bit history about it. In 930s itself the extrusion cooking is employed for production of pasta products by a continuous extrusion and in 1940s the cooking extruders for making puffed snacks, so in 1940s itself, they were used and in 60s only the low-cost extruder, simple low-cost extruders were developed. So this is the equipment, proper equipment which is exclusively used for the extrusion process for on farm cooking of soybeans used as a animal feed. So in 1960, the low-cost extruder is develop for on farm cooking of soybeans, so which is used as a animal feed.

A decade later, maybe 1970s the low cost extruder cooker technology was adopted and promoted by International agencies and government for the production of low-cost infant foods based on oil seed cereal mixture, oil seeds cereal mixture you can say the groundnut or seasame. So from there, they started producing the infant foods, so there the low-cost extruder cooker technology is used. Before that when it is used as animal feed maybe that hygienic processing conditions may not be needed but when it comes to infant foods proper GMP regulations should be followed in the equipment as well. So proper low-cost extruder cooker we started using in the food industry in 1970s to produce infant foods.

So extrusion cooking has been used to for that texturization of proteinaceous material of vegetable origin. So the extrusion cooking has been used to further texturization of proteinaceous materials of vegetable origin and also to produce meat like structures. So in the vegetable origin itself and extrusion has also been applied to the development of biodegradable and nano composite films with interesting barrier characteristics. So the vegetable origin material texturization also can be done, texturization in the sense giving proper texture to the material may be in the fibrous form, so that can be done and also the meat like structure in the vegetable origin food material itself.

So to look like or feel like it is a meat like food material and extrusion technology also apply to biodegradable and nano composite films. So this anyway we are going to see in subsequent lectures, the food packaging so these were all food packaging materials. In the sterilization or aseptic processing, itself, we have talked about much about the packaging because not only the processing is important to avoid further contamination packaging is also very much important. So nowadays the trend is to have biodegradable packaging to avoid the plastic materials, normal conventional plastic material because when you throw this into the environment, it also gets degrade easily.

In that way it will not cause any environmental pollution. So this extrusion technology is used to produce such kind of biodegradable films and nano composite films is which is produced using nano materials. The composite word is nothing but so combining 2 or 3 materials together to aim for particular application or advantages. For example, 1 particular biodegradable polymeric film is not having good oxygen permeability. Then I may add something or some other secondary material or secondary polymer to make this disadvantage of oxygen permeability into advantage. So for example for particular food material, I need to have oxygen permeability very low, so that I am not getting from using single biodegradable polymer I may add one more polymer to reduce the oxygen permeability of the particular biodegradable polymer.

So that means I am combining 2 materials to achieve a certain purpose of my application so that is nothing but a composite film. So if they are done using a nano materials, they are called nano composite films. So interesting barrier characteristic. Barrier characteristics only I told oxygen permeability and water vapour permeability, so everything called barrier characteristics, water vapor permeability, so there also extrusion technology is used. So basically to produce the film or food packaging films.

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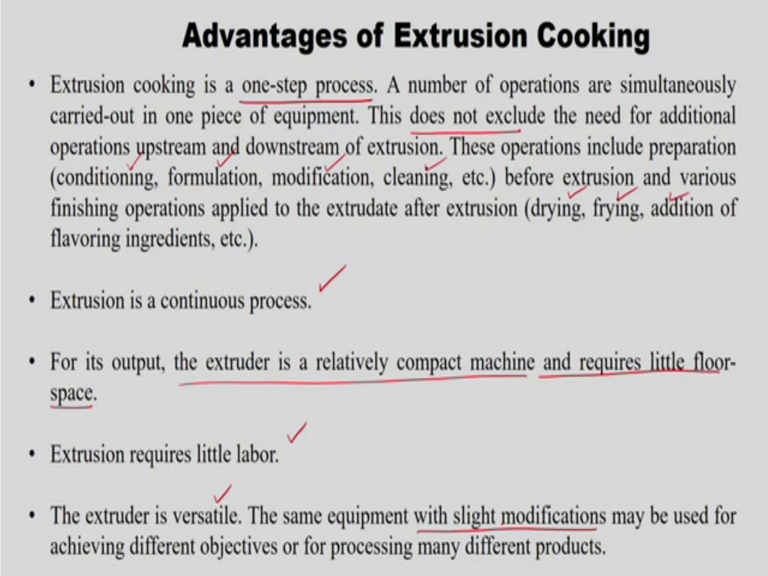

So extrusion cooking is one step process. So a number of operations are simultaneously carried out in one piece of equipment, so this does not exclude the need for additional operations upstream and downstream of a extrusion. So these operations include preparation, which is either done by conditioning, formulation, modification, cleaning etc. before extrusion and various finishing operation applied to the extrudate after extrusion, which is nothing but drying, frying, addition of flavouring agents etc.

So we said extrusion can take care of these processes together or alone, which is nothing but a cooking, sterilization, drying, melting cooling, texturing, conveying, puffing, mixing kneading etc., but one should not think that it also includes the upstream and downstream processing, so they should be carried out separately. So the upstream processing include conditioning, formulation, modification and cleaning and downstream processing or the finishing operations, which are applied to the extrudate after extrusion which are nothing but a drying, frying, addition of flavouring agents, this will be added after the extrudate comes out of the extrusion process.

So the next point is extrusion is a continuous process. For its output the extruder is a relatively compact machine because it also does many works together and requires little floor space and extrusion requires little labour, the extruder is a versatile equipment, the same equipment with slight modifications may be used for achieving different objectives or for processing many different products. As we said earlier these many process can be applied individually or together based on the need for the food material, food material processing.

So in that case with the slight modification these extruders can be used to for to achieve any different objective also to process any different products different products in the sense, so the same extruder can be used for puffing snacks as well as ready to eat cereals. The food processing, in the food processing of ready to eat cereals as well as the puffed snacks making we can use the same extruder and also the same equipment can be used for kneading as well conching as well. So different operations also can be done and different products also can be taken care with the single piece of equipment because it has got that kind of versatile in nature

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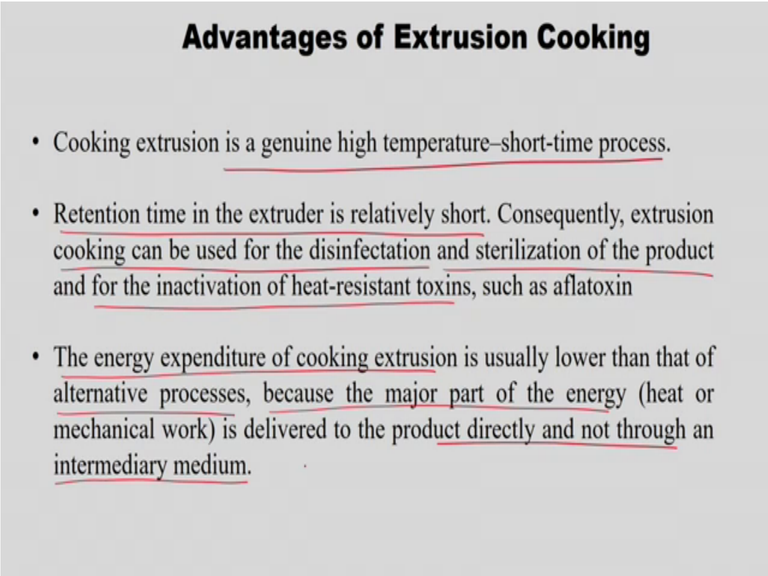

And cooking extrusion is a genuine high temperature short term process HTST, so their retention time in the extruder is relatively short. Consequently, extrusion cooking can be used for the disinfection and sterilization of the product and for the inactivation of heat resistant toxins such as aflatoxin. So extrusion also can be used for disinfection as well as a sterilization of the product and also it inactivates the heat resistant toxins, which is called aflatoxin.

The energy expenditure of cooking extrusion is usually lower than that of the alternative processes because major part of the energy heat or mechanical work is delivered to the product directly and not through an intermediary medium. So this is when compared to heat exchanger. So when you are melting the solid food particle or the moisturizing solids in the extrusion cooking, so it is like you are employing less energy expenditure in extrusion when compared to heat exchanger. First of all, handling high viscous material in heat exchanger is very much difficult, added to that heat exchanger got solid wall in between two fluids, so which adds extra resistance. So here the heat is directly applied. So in that way the energy expenditure in extrusion cooking is very much lower compared to alternative process.

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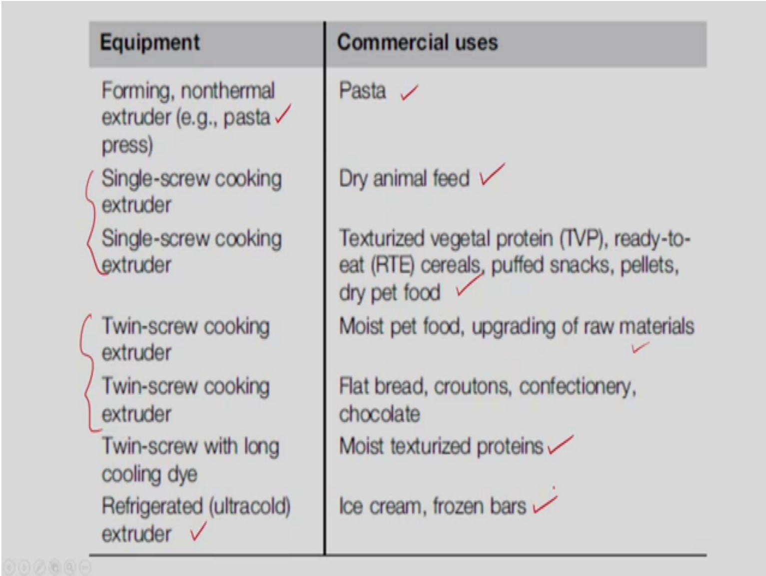

Equipment	Commercial uses
Forming, nonthermal extruder (e.g., pasta press)	Pasta
Single-screw cooking extruder	Dry animal feed
Single-screw cooking extruder	Texturized vegetal protein (TVP), ready-to-eat (RTE) cereals, puffed snacks, pellets, dry pet food
Twin-screw cooking extruder	Moist pet food, upgrading of raw materials
Twin-screw cooking extruder	Flat bread, croutons, confectionery, chocolate
Twin-screw with long cooling dye	Moist texturized proteins
Refrigerated (ultracold) extruder	Ice cream, frozen bars

And this is the history whatever we have discussed in a few slides earlier the forming or non-thermal extruder. This was first introduced as a extrusion equipment. So that was used for pasta then second one the single screw cooking extruder, which was used for dry animal feed and texturized vegetable protein and ready-to-eat cereal, puffed snacks, pellets, and dry pet food and after that the twin screw mechanism where included so this were used to moist pet food, upgrading of raw materials and flat bread, croutons, confectionery chocolate-making etc. and twin screw with long coolling dye that was used for moist texturized proteins and refrigerated extruder this is the latest technology ice cream and frozen bars. So these are all different kind of equipment and their commercial use.

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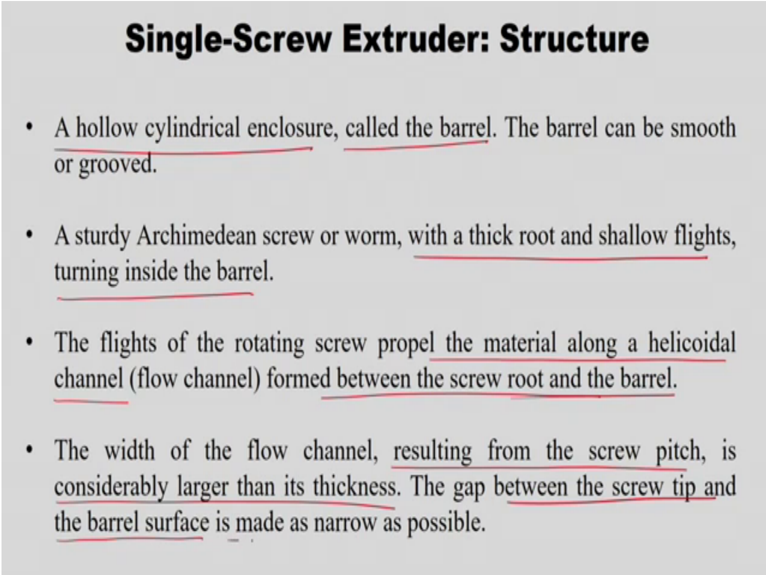

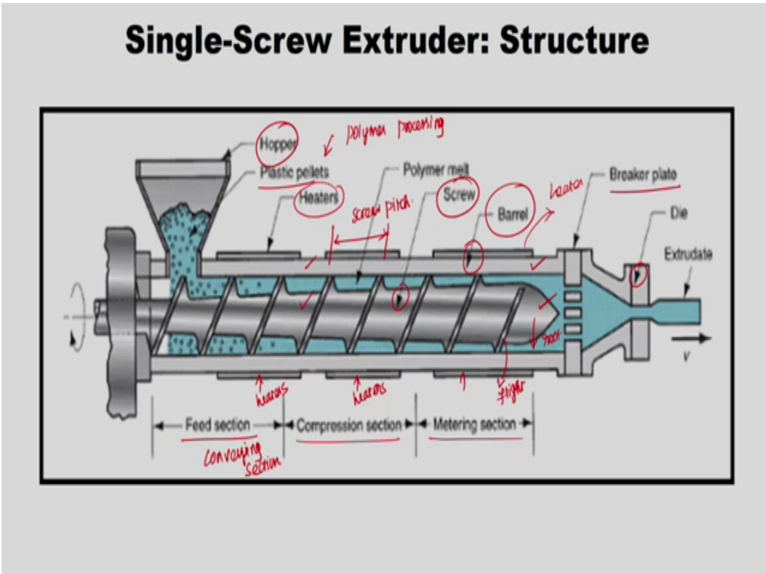

So we are going to see here for single extruder, single screw extruder as well as twin screw extruder, but not in detail because the extrusion technology in self a vast technology, which is also applied simultaneously in polymer processing which is called melt extrusion but here we are going to see what is the basic mechanism and what are all the thermal process or mass transfer or pressure changes or shear changes involved in, in the process of extrusion cooking and we also look into some of the physical and chemical effects.

So this is a single screw extruder so a hollow cylindrical enclosure called a barrel. The barrel can be smooth or grooved. So if you see here, so this is nothing but a barrel, so this can be smooth or grooved. A sturdy Archimedean screw or worm with the thick root and shallow flight, thick root and shallow flight turning inside the barrel. So if you see here, so this is nothing but a screw, so which has got thick root, so this is maybe we call it as a root and this is nothing but a flight.

A flights of rotating screw propel the material along a helicoidal channel, which is nothing but a flow channel formed between the screw root and the barrel, the screw route is this one and the barrel is this one so when it turns so the floor or food materials forming a helical flow section in between the barrel and the screw root, so the flights of rotating screw propel the material along the helicoidal channel formed between the screw route and barrel. So when it rotates the material also caught in between the helicoidal channel and it also moves forward from the feed side to end side of the extruder.

The width of the flow channel resulting from the screw pitch is considerably larger than its thickness. The screw pitch is nothing but the distance between two ply flights, so this is nothing but a screw pitch. So the width of the screw pitch is larger than its thickness. The gap between the screw tip and the barrel surfaces made as much as narrow as possible to employ high compression at the end of the extruder which is near the dye. So this is nothing but a dye, so which gives a proper shape for the extrudate. So this is a bigger plate anyway we are going to see what is the use of these materials.

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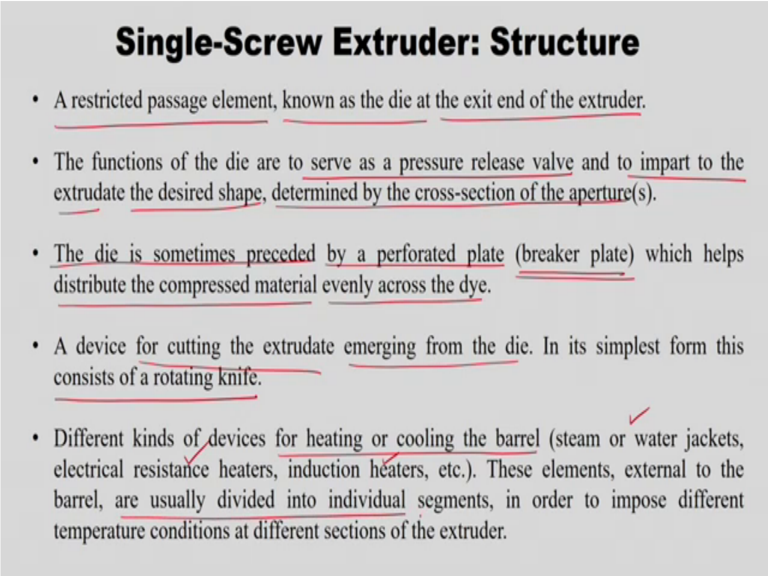

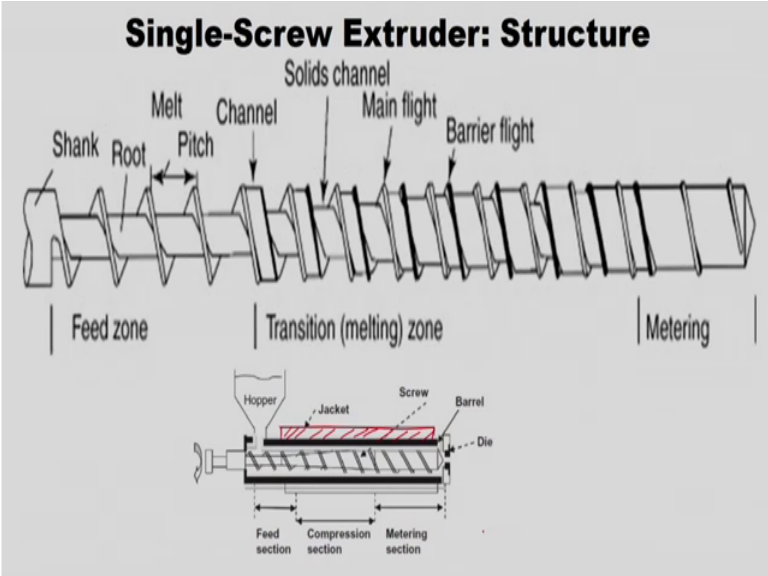

Restricted pay passage element known as a dye at the exit end of the extruder. So this is what we have seen here that is nothing but a dye, the functions of the dye are to serve as a pressure-release valve and to impart to the extrudate the desired shape determined by the cross-section of the aperture. So as I said earlier, so this dye gives the shape for the extrudate as well as so here when the material is coming near the beaker plate it has got high compression, high compression in the sense high pressure. So near the dye, it is released the pressure it acts as a pressure releasing valve. So pressure releasing valve and to impart to the extrudate the desired shape. The die is sometimes preceded by a perforated plate which is called a breaker plate. So the function of the breaker plate is nothing but to distribute the compressed material evenly across the dye.

So as I said here so the material comes near the breaker plate in the compressed stage, that means high pressure stage. So the breaker plate distributes them to the dye and a device for cutting extrudate at emerging from the die but here in this diagram it is not shown. So after it extrudate comes out of the extruder so there is a cutting mechanism usually It will be a rotating knife, so that is there. And different kinds of devices for heating and cooling the barrel. So as I said earlier the melting happens inside the extruder. So to get the melt from the plastic pellets, why plastic pellets initially extruders were used in the polymer processing I just told.

So here food material anyway, we are going to see as in with the examples. So when food material flows along the extruder the heater melts them and move them forward till the end of the extruder. So for that reason either it may be a jacket, jacket in the sense, for example here the different extruders I have put here so here if you see the jacket jacket in the sense single channel so through which either hot water or steam will be flowing or you may get here it is a, so here these are all heater or coolers, we call it as a segmental heaters or segmental coolers.

So based on the applications sometimes it is done in the cold, I mean the coolers are also needed. Sometimes we call it as a cold extrusion one example is there we are going to see, so you can use it as a segmental heaters or you can use that as a jacket through which heating or cooling medium can be passed depending upon the application, so different kinds of devices for cooling and heating which is kept in the barrel. So either it is a in the form of steam or water jackets electrical resistance heaters, induction heaters. So electrical resistance heat us your barrel can be bound by the electrical coils as well.

So that kind of mechanism also there, these elements external to the barrel are usually divided into individual segments, that is what I call it as segmental heaters in order to impose different temperature conditions at different sections of the extruder. So for example, I need initially high temperature and at the end low temperature means this heater can be designed with the higher voltage and this heater can be designed with a lower voltage. So the segmental heater advantage is that, so that cannot be done using throughout the jacket in here. So here the steam or hot water may be flowing with the same temperature.

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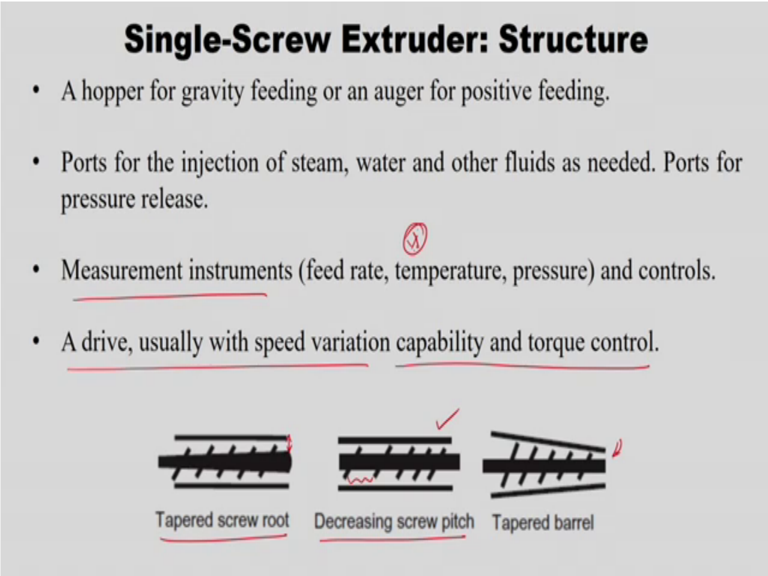

A hopper of gravity feeding or auger for positive feeding, so the hopper is this. So this is nothing but a feeder for the extruder and a ports for the injection of steam, water and other fluids as needed. So if you have got jacket, then there should be port through which the stimulus employed and measurement instruments, this is very much important flow rate measurement, temperature measurement, pressure and associated controls. Drive usually with speed variation capability and torque control also needed.

So we have got three figures, the first one I have explained so this is the food material, this is hopper, so this is your screw, screw has got root as well as flights. So the flow channel is formed into between the barrel and the screw route and segmental heaters are employed in the barrel then anything we remote and once it starts it starts with the feed section. So sometimes it is called as a conveying section as well.

So where there where there your feed, feed food material is conveyed to the next section. So this is a compression section. So here only the compression starts if you see the screw has expanded in diameter when it is along the length of the screw along the length of the screw it has expanded in diameter, the diameter at the end of the screw is higher than the diameter at the feed. So the flow channel is formed between barrel and the screw root and when you go near to the end of the extruder this flow channel height or the distance between the barrel and the screw rate is reducing that is the way it is compressed.

So the heater which is kept in the surface of the barrel heats the material that is the way melt is being formed. The second section is compression section. The third one is metering section that is properly compressed at melted region, and here if you see that this shank, shank is nothing but a head material here. So this is root this we have told already the melt and the pictures the distance between two plates and channel is nothing but which was formed in the between the root and the barrel and barrier flight main flight.

So if you see here the distance between two flights is higher in the feed section, feed zone but when you see here in the transition as well as metering zone the distance that is pitch, between two flights with decreased to give proper compression. So feed section, compression section, metering section, barrel die. So this we have seen there itself. So here also this breaker plate distributes the material to the die, die gives proper shape as well as the pressure releasing. So from the compressed food material, so that is the function of dye and extrudate once it comes out of the extruder the rotating knife cuts the extrudate based on the shape.

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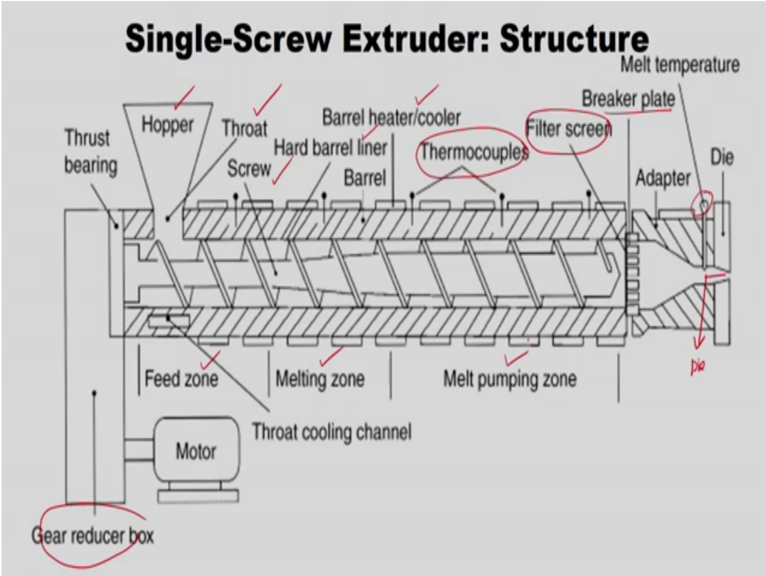

So here what the gear reducer box, so this is operated by the motor so which gives the rotation to the screw. So otherwise we have seen hopper, throat section, screw, hand barrel line and barrel heater and cooler and thermo couples for the temperature control and here it is a filter screen. So before going into breaker plate or distributor plate and there is a adapter so this is nothing but a die. So which gives the proper shape and this is a distributor plate and this is adapter the melt temperature to measure the melt temperature the thermo couple is employed here and feed zone or conveying zone, so this is a melting zone the melt pumping are metering zone, so that is all about.

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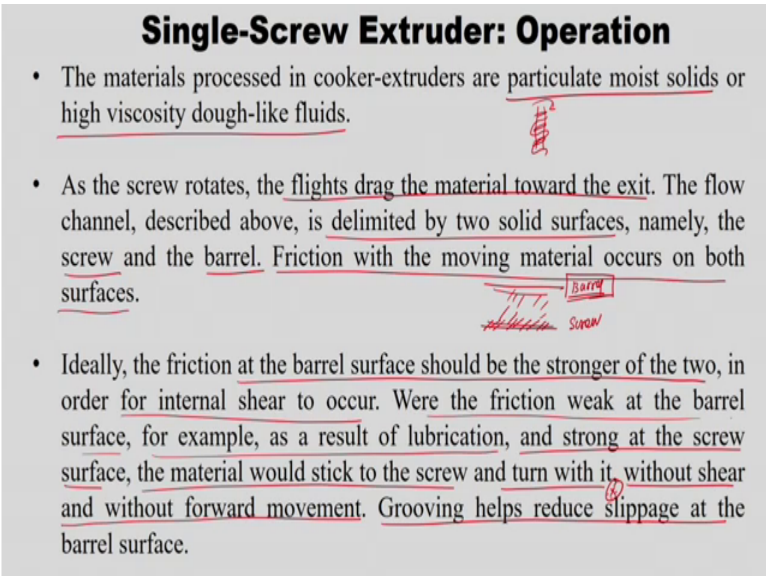

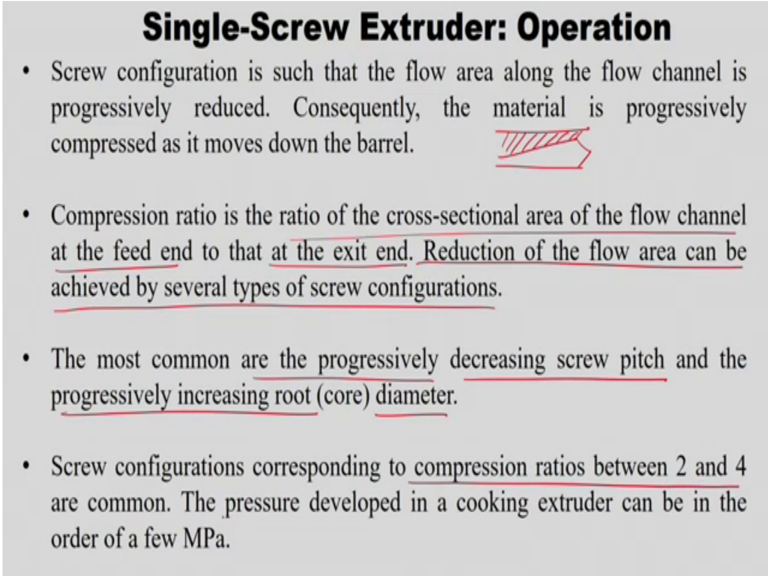

The materials processed in cooker extruders or particulate moist solids as already told and high viscosity dough like fluids. So it is the viscosity of the material is so high and as the screw rotates the flights drag the material toward the exit. So this what we have told so this is the screw so this is your flight so when it rotates so it drags the material toward the exit of the extruder. The flow channel described above is delimited by two solid surfaces, one is, another one is the screw root. The friction with the moving material occurs on both the surfaces, so this normal phenomenon.

So you have a you have got a barrel, this is your screw, so the material is cut in between so when the material is flowing along the barrel surface as well as in the screw surface, so there is a friction, right. Ideally friction at the barrel surface should be the stronger of the two, because the screw is rotating here, so the friction produced by the barrel should be stronger for internal shear to occur but where the friction weak at the barrel surface for example as a result of lubrication and the strong at the screw surface the material would stick to the screw and turn with it without shear and without forward movement.

So what it is told, when the material is caught between the barrel and the screw, so the friction is generated in both the surfaces, so ideal condition, the barrel friction should be higher and stronger in order to move the food material further near to the end of the extruder but what may so happen is, the friction generated in the barrel may be weaker due to many reason. One such reason is lubrication and also here when we discuss about the single screw so we also told one condition it may be of smooth surface or grooved.

If it is a smooth surface, then the friction may not be that stronger in the barrel. So in that case if my screw got stronger friction the material stick to the screw instead of forward movement, it rotates along with the screw. So that is the condition happens when barrel but low or weak friction compared to screw. Grooving helps reducing slippage at the barrel surface, so that is why your barrel's surface should be grooved to avoid such kind of situations. Such kind of situation is here is, the food material tend to stick to the screw and try to rotate instead of moving forward.

So screw configuration is such that the flow area along the flow channel is progressively reduce this I have told you because the screw got increase in diameter along the length of the extruder so that way your flow channel between barrel and screw gets reduced. The material is progressively compressed as it moved down the barrel so when the place is getting reduced, so it is compressed more the compression ratio is the ratio of cross sectional area of the flow channel at the feed end and at the exit end between the feed and exit end. So the reduction in cross sectional area is nothing but a compression ratio.

Reduction of the flow area can be achieved by several types of screw configuration. So that is what here it is shown, one is tapered screw root. So that is what we have seen in all those three figures. So it has got increase in diameter, that is the way the distance between the barrel and the screw root is getting reduced. So that is one kind of compression. The second kind of compression is pitch screw pitch is reduced along the flow length, along the length of the extruder.

So in that way also by decreasing screw pitch, you can create the compression and another is tapered barrel, but this is not common normally because the normal design or industrially apply design is the barrel got parallel plates only the screw can be tapered or screw pitch can be reduced but this design is also there but not largely used in the industrial purpose. The most common or the property decreasing screw pitch and the progressively increasing root or core diameter the screw configurations corresponding to compression ratios between two and four are common and the pressure developed in the cooking extruder can be in the order of few mega Pascal.

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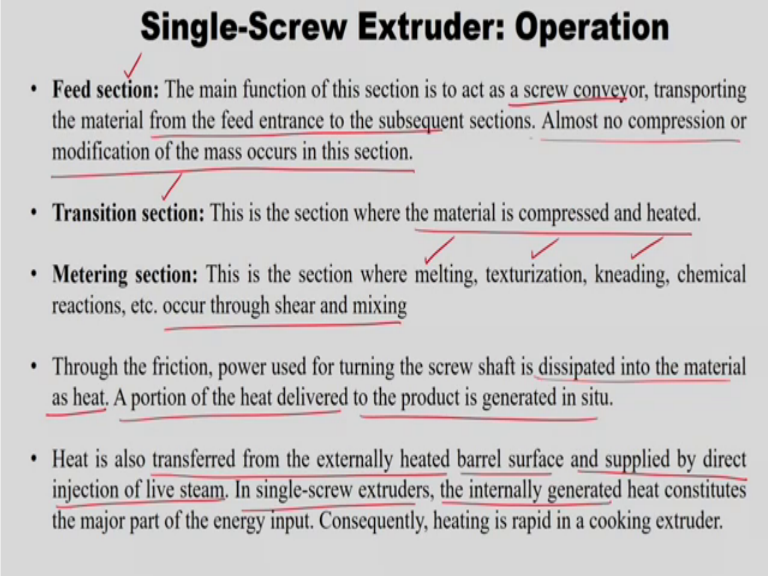

So the sections wise one is feed section. So the main function of this section is to act as a screw conveyor. So it just conveying the feed material from the feed end into the exit end of the extruder transporting material from feed entrance to the subsequent sections, sorry, it is a subsequent section, it is not end so it is conveying material from the feed inlet to the next section, which is nothing but a transition section. Also no compression or modification of the mass occurs in the section. So no heat is employed in the food material and no melting or no mass change. So only it conveys the food material from the feed section to the transition section. In the transition section the material is compressed and heated.

In the metering section so the melting happens, texturization, kneading, chemical reactions etc. happens through shear and mixing in metering section. Through the friction used for turning the screw top is dissipated into the material as a heat. So as I said here we are using the shaft mechanism so here using the thrust bearings, so we are giving the rotation to the screw. So whatever power you are giving here due to the friction there is a dissipation happens. So the screw shaft is dissipated into the material as a heat. Due do friction the heat is generated, so the power you are given to rotate the shaft is dissipated as a heat.

The portion of the heat delivered to the product is generated in situ. So we have employed the segmental heaters or jackets to heat the material or melt the material but some of the heat also generated in situ from the power which is given for turning the screw shaft, heat is also transferred from the externally heated barrel surface and supplied by direct injection of the livestream. So this we have discussed either segmental heaters or by jackets in which the live stream is flowing. In single screw extruders, the internally generated heat constituents are major part of the energy input, consequently the heating is rapid in the cooking extruder.

So it is not only melting is happening by the segmental heaters employed in the barrel surface or the heating medium employed through the jackets. The sum of the heat is being employed to the material by the heat which is generated from the friction which is coming from dissipation of the power given to the screw shaft. In such cases the heating is very rapid in the cooking extruder because it is not depending upon the external heating medium. It itself generates the heat and melts the product.

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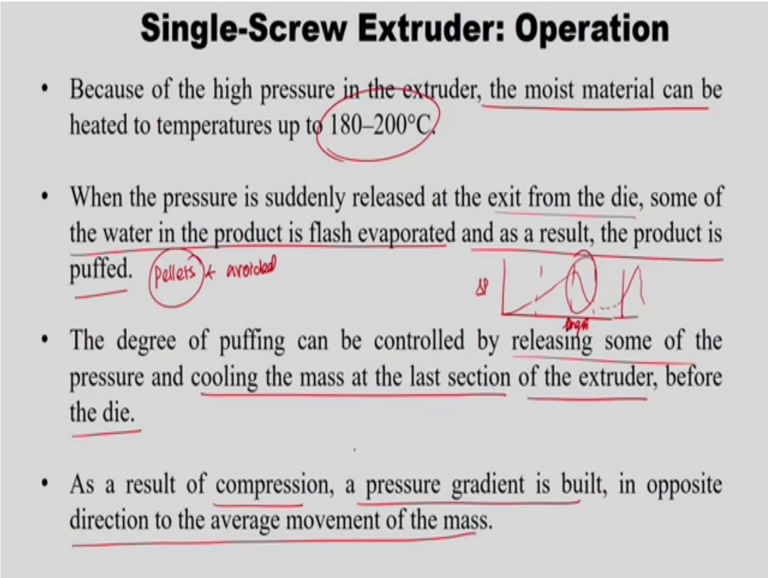

Because of high pressure in the extruder the moist material can be heated up to the temperature of 180 to 200 when the pressure is suddenly released at the exit of the die the some of the water in the product is flash evaporated and as a result the product is puffed. So this particular mechanism also we have seen whenever the pressure is reduced the water is getting flash evaporated. So in that case the product became puff, the product will be swollen, but if you want to pellet size material or product, so this should be avoided.

So this is this should be avoided when you need a pallet. So if you need your products in the form of pellets form so this should be avoided. So the degree of puffing can be controlled by releasing some of the pressure and cooling the mass at the last section of the extruder before the die. So, for example, what they were saying is this is the length and this is pressure. So we have got three sections, one is conveying section, so then the transition section, so here the also pressure is increase.

So then there may be a venting section where the pressure will be reduced then further it is conveyed and in the compression section the pressure maybe increase. So in that way so if I went some of the pressure controlled by releasing some of the pressure cooling the mass at the last section of the extruder we can avoid this puffing, when you need a pellet size material at the end of the extruder, as a result of compression, your pressure gradient is built in the opposite direction to the average moment of the mass. So what we told in the extruder the feed is fed in the hopper.

So in the conveying section, it is conveyed to the transition section, in transition section the pressure and temperature of the fluid will be increased and in the metering section, the melt is formed and compressed and further compressed before going in to die to get the proper shape but as we told the compression is increased along the length so it is creating a pressure gradient opposite to the direction of the average movement of the mass. So that means so your end of the extruder the pressure is high near the inlet the pressure is low automatically backflow happens.

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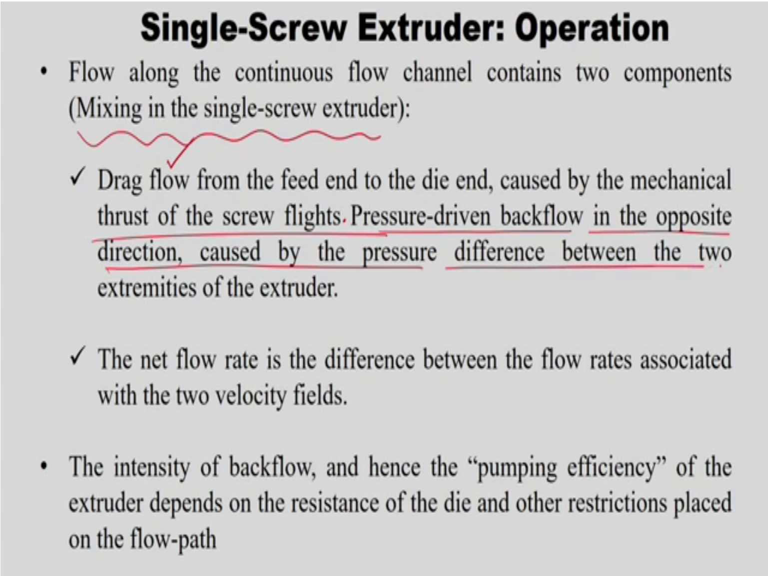

The flow along the continuous flow channel contains two components. So normally which also helps mixing in the single extruder, one is drag flow from the feed end to the die end caused by the mechanical thrust of the screw flights. So we already told when the screw is rotating the material is get caught between the barrel and screw root surface and that is the way it is moving forward near to the die but at the same time the pressure driven back flow in the opposite direction caused by the pressure difference between the two extremities of the extruder so at the end of the extruder, pressure is high and the inlet of the extruder the pressure is low, so because of that some backflow also happens. So forward movement is also there, backward movement of the fluid is also there.

The net flow rate is the difference between the flow rates associated with the two velocity field; one is due to drag flow another is due to back flow. The intensity of back flow and hence the pumping efficiency of the extruder depends upon the resistance of the die and other restrictions placed on the flow path. The intensity of the back flow and hence the pumping efficiency, pumping efficiency in the sense, so taking the material or metering at the end of the near the end of the extruder. So that is depends on the resistance of the die because this causes the further resistance to the flow and other restrictions placed on the flow part.

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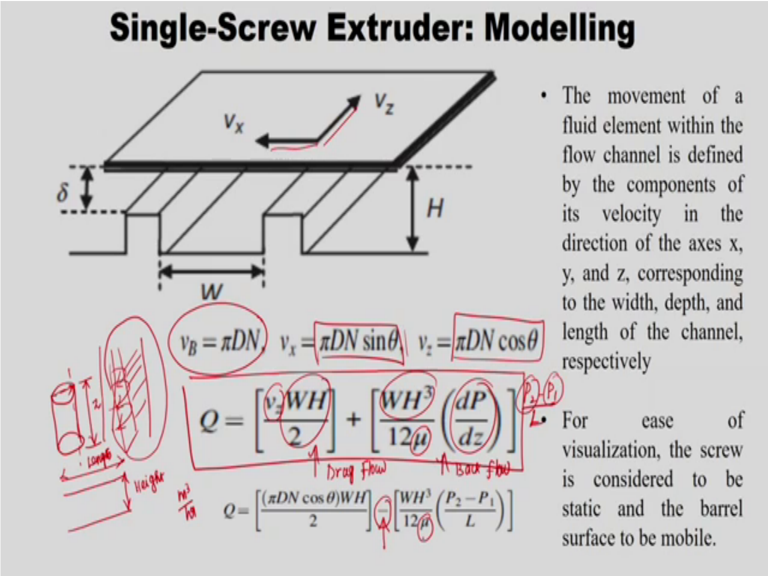

So this is simple modelling. But remember so this here we are going to see the volume throughput of the single screw extruder. So here this model is done based on certain assumptions. So one has to be very careful when you use this model as I said in membrane separation lecture itself. So there also be used to Darcy model, (()) (41:21) model. So everything has got certain assumptions, so remember when these models were used those assumptions should be kept in mind. So here what we did, so here I have a barrel surface, so here is my screw so in between my flow channel, so the screw is also rotating. In between my fluid our food particles get caught.

So this we call it as a flow channel. So this flow channel is filled and kept as a rectangular channel, rectangular channel in the sense, for example, you have got a cylindrical section, so if you cut it here, so what you make is the rectangular thing, so this is nothing but you are z.

So the z becomes height here. So this see this is your, the radius or diameter. So the diameter becomes the length here, so that is what we have done here, so we made it as a rectangular channel. So this has got three velocity components one along the length and another along the width and another along the height the one along the height we are not taking into account here.

The total velocity is nothing but a pie DN and so pie D is the circumference so N is nothing but a number of rotations. So when you got two components one is pie DN sin theta which is nothing but a Vx, the (Vu) Vz is nothing but pie DN cos theta so when you come and apply in the volumetric throughput, so this is nothing but a volumetric flow rate so meter cube per second or hour, so which is nothing but a velocity meter per hour into area, so which is nothing but meter square, so meter cube per hour, so this is due to drag flow, drag flow, so which is nothing but Vz WH upon 2. The second one is due to backflow, back flow is happening due to pressure gradient.

The pressure gradient is dP upon dz, z is along the length, dd a set of nothing but pressure gradient. That means P2 minus P1 divided by length. So this P2 is nothing but pressure at the end of the extruder, P1 is at the feed side. So the length is nothing but length of the extruder, WH cube upon 12 mu, mu is nothing but the resistance which is nothing but a viscosity here, W is width of the flow channel, H is nothing but a height of the flow channel. So your final equation looks like pie DN cos theta, Vz is it is here by DN cos theta WH upon 2. So why this minus, this minus because so drag flow plus back flow, but backflow happens in the opposite to the forward movement of the food material. So because of that it is a minus W H cube divided by 12 mu, mu is nothing but a viscosity of the material P2 minus P1 upon L.

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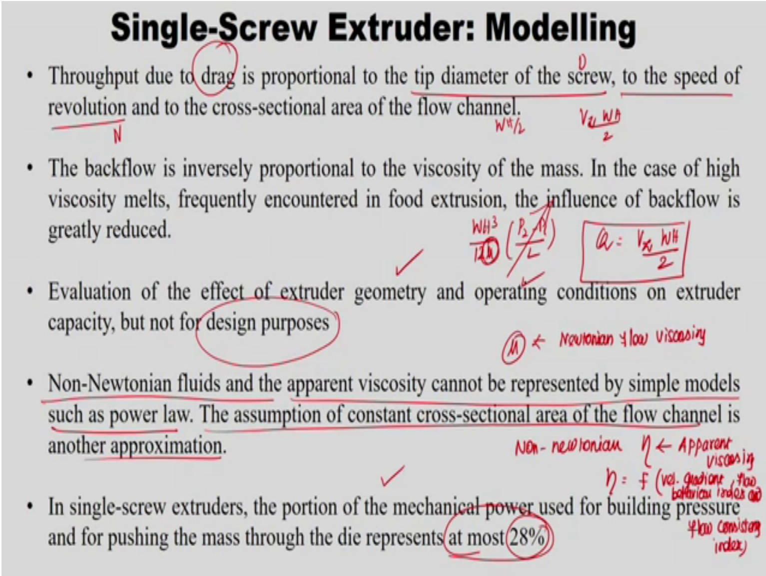

So throughput due to drag is proportional to the tip diameter of the screw. This is nothing but a capital D and the speed of rotation, revolution or rotation, which is N and to the cross sectional area of the flow channel, which is nothing but WH by 2, so that is due to drag because we have seen Vz WH upon 2. Backflow is inversely proportional to the viscosity of the mass because for this contribution, WH cube 12 mu into P2 minus P1 upon L.So in that case, so this is inversely proportional to the viscosity of the mass. In case of high viscosity melts so if the viscosity is high, so this term will be very much low, so in that case you can directly calculate Q as a Vz WH upon 2 because the viscosity is high this term got very less weightage in the Q so you can go by Q is equal to Vz WH upon 2.

Evolution of the effect of extruder geometry and operating conditions on the extruder but not for the design purpose, this I have already told so you cannot design a extruded based on this particular formula, so it can be used to check the effect of extruded geometry. For example, if increase the theta, theta is nothing but here the flight angle. So angle between the flight or you can call it as a screw angle. So if I increase the length of the extruder what happens, the comparative study you can do or you can check the operating conditions.

For example, in this particular extruder how much of the material can be fed. So these thing you can use this equation and calculate, but not for the design purpose because it has got its own assumptions. The one of the assumption is Non-Newtonian fluids and the apparent viscosity can be represented by simple models such as power law. So here we are still using mu, mu is nothing but a Newtonian fluid viscosity, Newtonian flow viscosity, but most of the food material and also we told and especially for extruder we use for high viscosity food material.

So most of the food materials are Non-Newtonian fluid. So in the Non-Newtonian fluid if you remember our earlier classes, we use apparent viscosity, which is nothing but eta, so this is called apparent viscosity. So apparent viscosity is nothing but a function of velocity gradient, flow behaviour index and flow consistency index. So here we are still using mu so that is not correct and the assumption of constant cross sectional area of the flow channel. So we are considering constant cross sectional area, we our self know the cross sectional area decreases when the material is passed from feed side to extruder end but here we are considering the assumption of constant cross sectional area.

In single screw extruders the portion of the mechanical power used to for building pressure and for pushing the mass through die represent at most 28 percentage. So this means this we have seen so whatever the power we are giving for the screw to rotate that is nothing but a mechanical power used for building pressure and pushing the mass through the die represent almost to 28 percentage. So the remaining is dissipating as a heat. So that is why the single screw extruders the heating is very much rapid, almost a 72 percentage of the power given through the extruder is dissipating as a heat.

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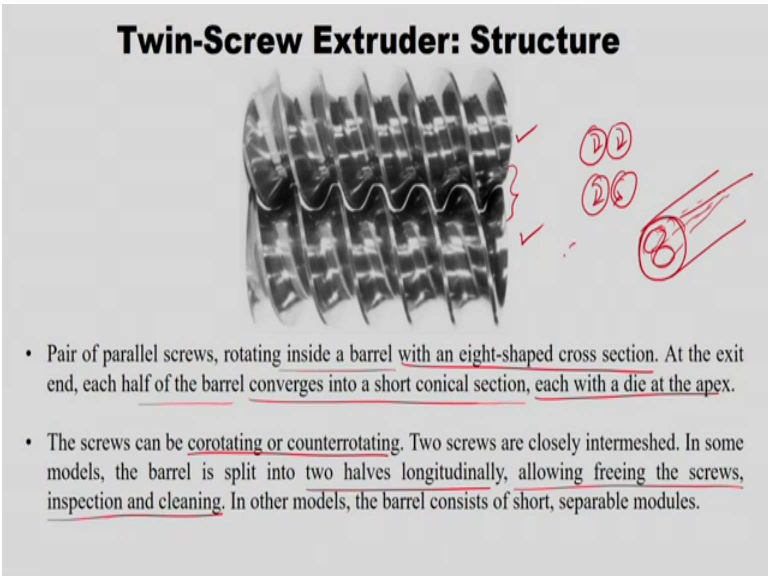

So this is a twin screw extruder so if you see so this is one particular screw, this is another screw, pair of parallel screws rotating inside the barrel so instead of one with an 8 shaped cross section. So this is your barrel, so you got two screws together, so this got, so if you see the side view so you will see like a 8 shaped cross section. At the exit end each of the half of the barrel convert into a short conical section each with a die at the apex. So if you see in the single screw extruder, so it also got the final conical section. So this is the employed for both the screws, this way the screw is tapered in both the screws.

The screws can be co-rotating and counter rotating so that means so both screws can be co-rotating in the same direction, or one screw rotates in this way and another screw rotates in this way, counter rotating as well. The two screws are closely intermeshed so you can see here and in some models the barrel is split into two halves longitudinally allowing freeing the screws, inspection and cleaning. So this has got many design. So I request you to refer some of the books if you want to get in detail or if you are working particularly in extrusion technology. So here we are not discussing much depth about the each equipment. So in one of the models the barrel itself, there it is a cylindrical barrel. So here the barrel itself a half half of the barrel. So once for the cleaning what it has been done is so half of the barrel can be removed and the screw is taken out and cleaned for proper cleaning. So that is what it is to halves longitudinally allowing freeing the screws inspection and cleaning.

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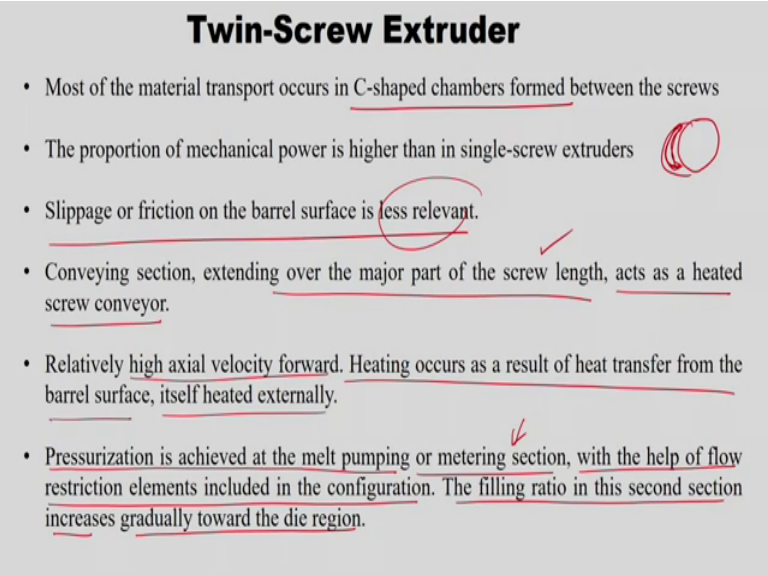

In other models the barrel consists of short and separable modules. So for example, so this is one kind of barrel and this is another kind of barrel. So this is module wise, so you can easily remove and clean and most of the material transport occurs in the C-shaped chambers formed between the screw, so that means so you have got one screw here the other screw here, so in that case so your material is get caught between the C-section. So or you can see probably here, so this is what they call it as a C-section. So your material is get caught in the C-section.

The slippage or friction on the barrel surfaces less relevant here so that is not even taken into consideration because that is taking care by the intermeshed screws because why we are thinking about slippage or friction is the fluid or the food material is sticking to the screw and it is not having a forward moment but here the material is get caught in between the screws and both screws are rotating so this is less relevant and conveying section extending over the major part of the screw length acts as a heated screw conveyor in case of twin-screw relatively high axial velocity forward compared to single screw extruder, heating occurs as a result of heat transfer from the barrel surface itself heated externally.

So since you have a two screws that means twin screw, so you are whatever the pumping power you are applying so that will be consumed by the two twin screw compared to single screw. So in that case the dissipation of the mechanical power given to the screw will be reduced in this twin screw extruder combination in that way you supposed to employ more heat to the product using either segmental heaters, which is placed in the barrel or using a jacketed vessel with the proper heating medium. So that is what it is told.

Pressurization is achieved at the melt pumping or metering section with the help of flow restriction elements included in the configuration. The filling ratio in the second section increases gradually toward the die region, so that heat transfer wise here we told the heating occurs as a result of heat transfer from the barrel surface itself heated externally because the amount of pumping power we were given is consumed by the twin screw. So in that case the dissipation also less so the heating to be employed externally and pressurization is achieved at the melt pumping or metering section.

So this is common for both single extruder as well as the twin screw but if you see there is a section called transition section. So the transition section your pressure is increased, your temperature is increased but here the pressurization is achieved at the melt pumping or metering section, that is the third section with the help of flow restriction elements included in configuration. The filling ratio in the second section increases gradually toward the die region. So the conveying section we told it is so extended over the screw length and pressurization is happening at the metering or melt pumping section.

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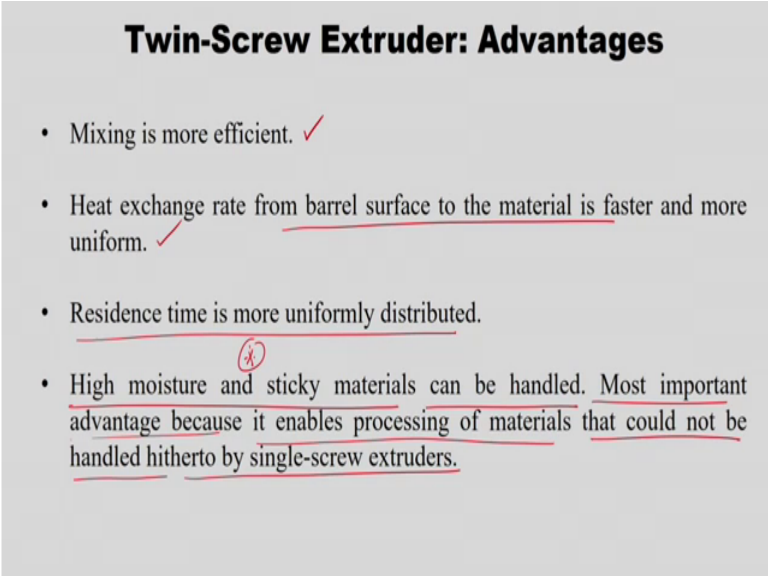

So advantages of twin screw extruder over the single screw extruder is mixing is more efficient and heat exchange because of twin-screw heat exchange rate from barrel surface to the material is faster that we know and more uniform because of twin screw mechanism. Residence time is more uniformly distributed because no residue stick to the screw because both the screws were rotating. High moisture sticky materials can be handled, so this sticky material sometimes problem when you handle in the single screw extruder, we told why it is because sometimes it gets stick into the screw and rotating instead of forward movement, most important advantage of twin screw extruders is it enables processing of materials, that could not be handled hitherto by single screw extruders. So that is nothing but a high moisture sticky materials.

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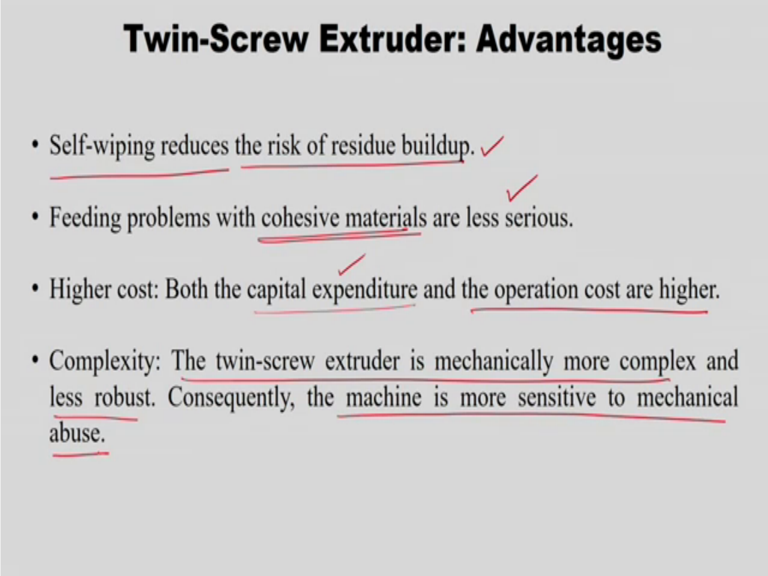

So then twin screw extruder the more advantage is self-wiping, reduces the risk of residue build-up and self wiping is nothing but one is wiped using other screw the whatever the material sticking into one screw is wiped by the another screw itself. So which reduces the risk of residue build-up and feeding problems with cohesive materials are less serious. So handling these cohesive materials are less serious in twin screw and a disadvantage wise these are higher cost because the capital expenditure and the operation costs are higher because of twin screw mechanism and twin screw is mechanically more complex and less robust consequently the mission is more sensitive to mechanical abuse. So that is the complexity in handling when screw extruder.

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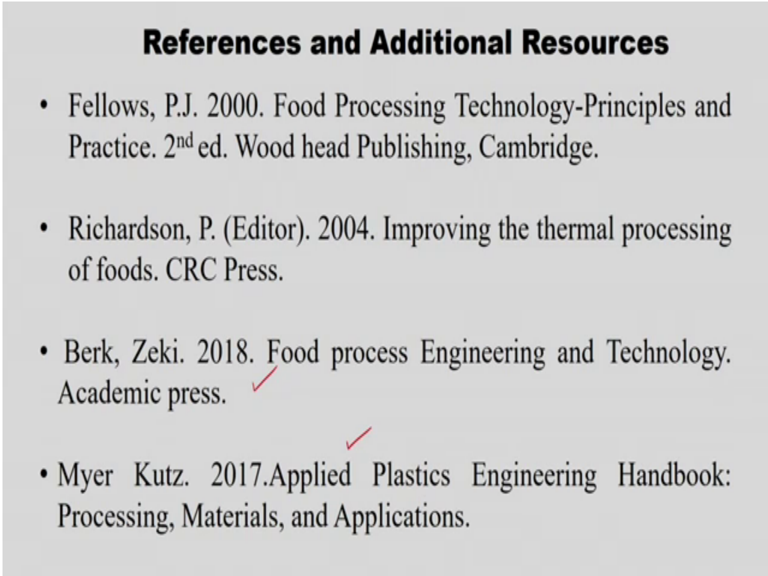

So for this lecture this is the references and additional resources and the figures what we have shown single screw extruder taken from this particular book, and otherwise, the material is taken from Berk, Zeki, and some of the points are also taken from Fellows and Richardson. Thank you.