Novel Technologies for Food Processing and Shelf Life Extension
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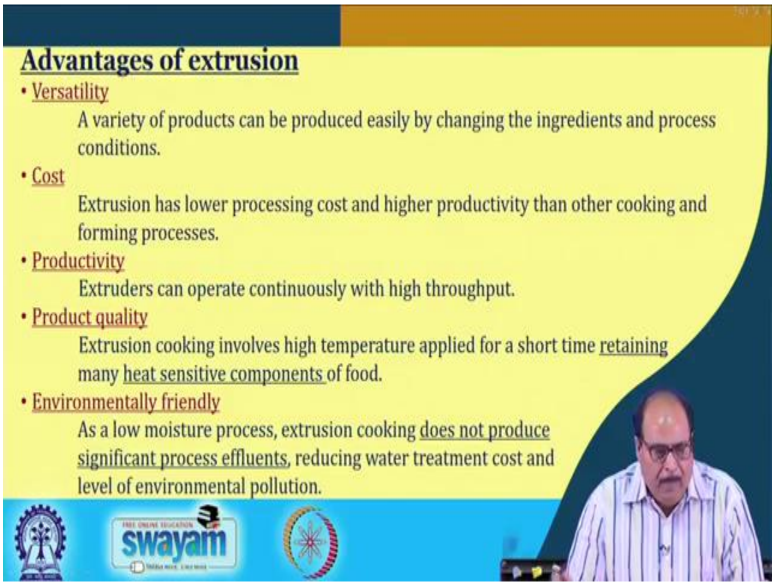
Lecture – 23
Extrusion Technology (Part 1)

Extrusion is a versatile technology used for manufacture of variety of food products. In two parts, the extrusion technology is discussed. In this part, the basics engineering and technological principles of food extrusion and also about the different types of extruders are explained. In the second part, the effect of extrusion on food characteristics, food components, raw ingredients suitable for extrusion and the product characteristics is elaborated.

Extrusion technology

Food extrusion is a versatile high temperature short time process which has become established for continuous manufacture of new and traditional products. In extrusion cooking, the food material is heated either by external heat source or by heat produced through dies to expand and extrude in desired shape. Extruder is used to produce extrudate of different shapes by forcing a specially designed opening after a previous heating of the material.



Advantages of extrusion

- **Versatility**

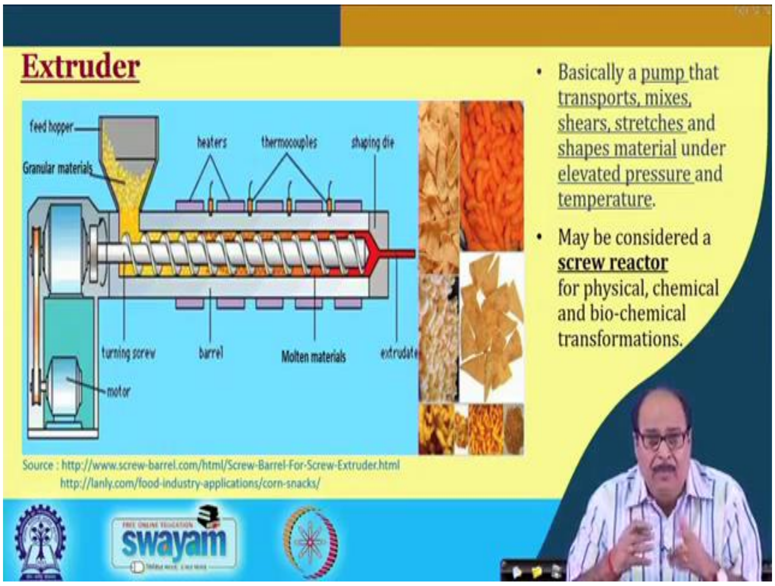
  A variety of products can be produced easily by changing the ingredients and process conditions.
- **Cost**

  Extrusion has lower processing cost and higher productivity than other cooking and forming processes.
- **Productivity**

  Extruders can operate continuously with high throughput.
- **Product quality**

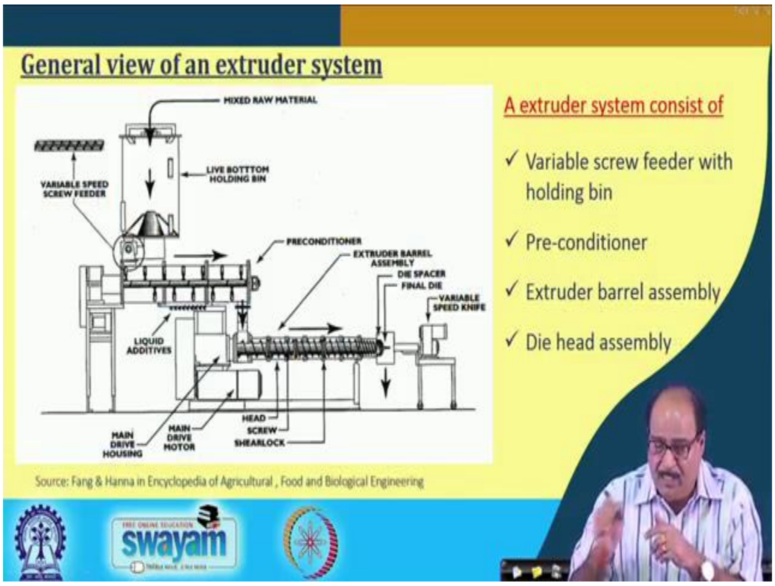
  Extrusion cooking involves high temperature applied for a short time retaining many heat sensitive components of food.
- **Environmentally friendly**

  As a low moisture process, extrusion cooking does not produce significant process effluents, reducing water treatment cost and level of environmental pollution.



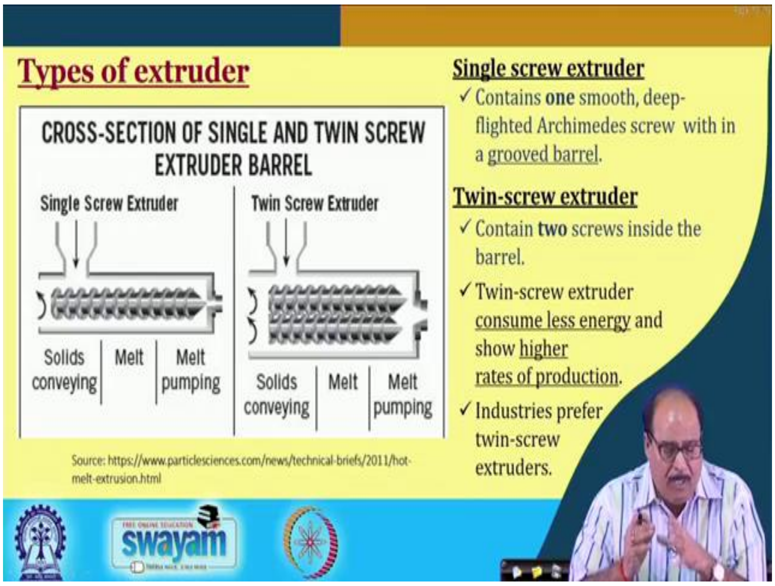
Extruder

The extruder machine is basically a pump that transports, mixes, shears, stretches and shapes material under elevated pressure and temperature. In fact, this is single machine in which more than one unit operations take place simultaneously. And this extruder can be considered a screw reactor for physical, chemical and biochemical transformations of the materials.



General view of an extruder system

Extruder system consists of a variable screw feeder, holding bin, pre-conditioner, extrusion barrel assembly and die head assembly. Feed material from hopper is fed to pre-conditioner where the moisture is adjusted and further it moves to extrusion barrel assembly. Appropriate conditions i.e. process and system parameters are maintained to get the desired characteristics of the end product. Finally, the material is forced through a specially designed die assembly to get predefined shape.

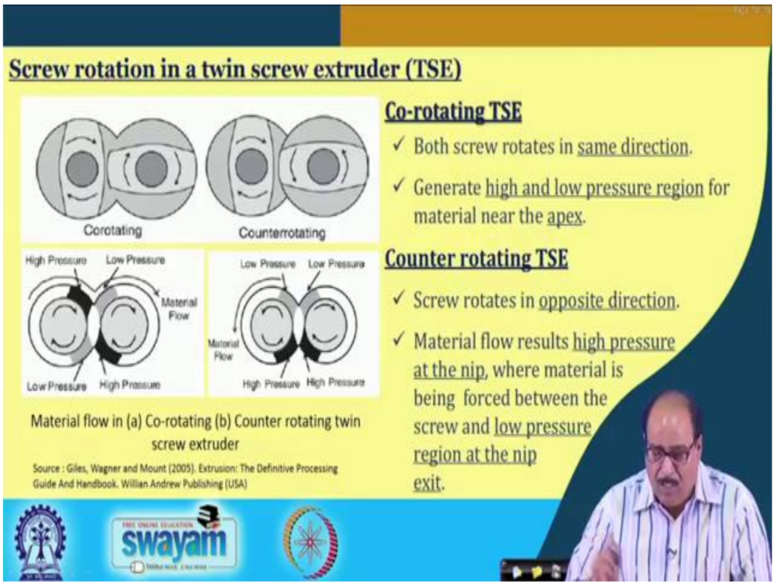


Types of extruder

There are two types of extruder i.e. single screw extruder, and twin screw extruder used widely in food industry.

(i) Single screw extruders – It contains one smooth, deep flighted Archimedes screw within a grooved barrel (see figure).

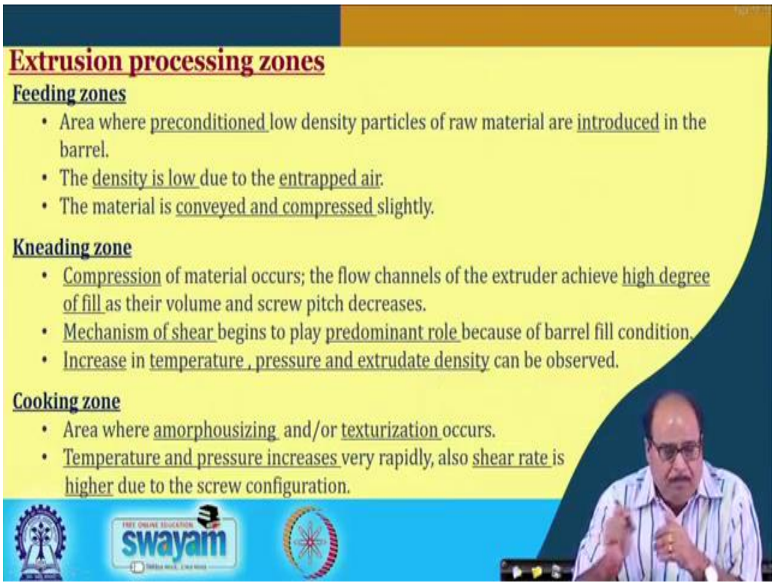
(ii) Twin screw extruders – It contains two screws inside a barrel. It consumes less energy and shows higher rate of production, therefore, industries widely prefer twin-screw extruders.



Screw rotation in a twin screw extruder (TSE)

The twin screw extruder may be a co rotating type or counter rotating type.

- **Co-rotating TSE**
  - ✓ Both screws rotate in same direction.
  - ✓ Generate high and low pressure region for material near the apex.
- **Counter rotating TSE**
  - ✓ Screw rotates in opposite direction.
  - ✓ Material flow results high pressure at the nip, where material is being forced between the screw and low pressure region at the nip exit.



Extrusion processing zones

1. Feeding zones

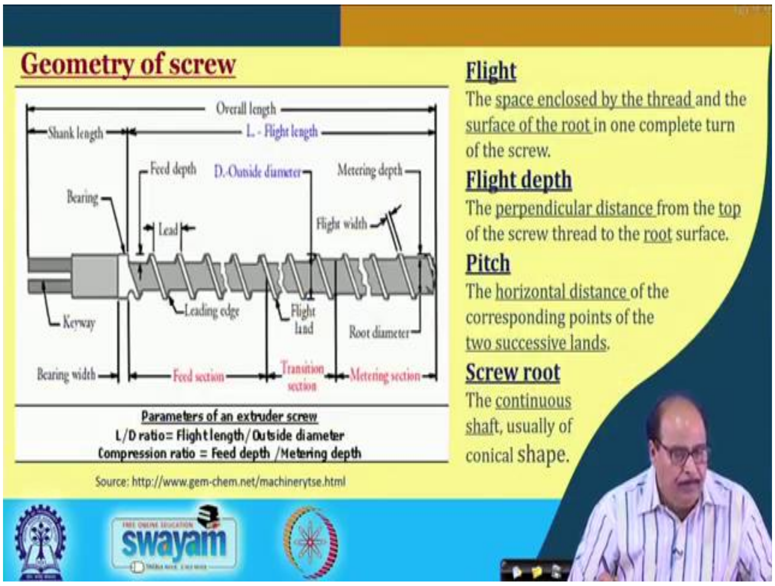
- Area where preconditioned low density particles of raw material are introduced in the barrel.
- The density is low due to the entrapped air.
- The material is conveyed and compressed slightly.

2. Kneading zone

- Compression of material occurs; the flow channels of the extruder achieve high degree of fill as their volume and screw pitch decreases.
- Mechanism of shear begins to play predominant role because of barrel fill condition.
- Increase in temperature, pressure and extrudate density can be observed.

3. Cooking zone

- Area where amorphousizing and/or texturization occurs.
- Temperature and pressure increases very rapidly, also shear rate is higher due to the screw configuration.



Geometry of screw

In order to get the desired characteristic of the product and to understand the mechanism of the extrusion process, it is essential to understand the geometry of screw (see figure). The different terminologies related to the extruder screws are described below:

1. **Flight**

   It is the space enclosed by the thread and the surface of the root in one complete turn of the screw.

2. **Flight depth**

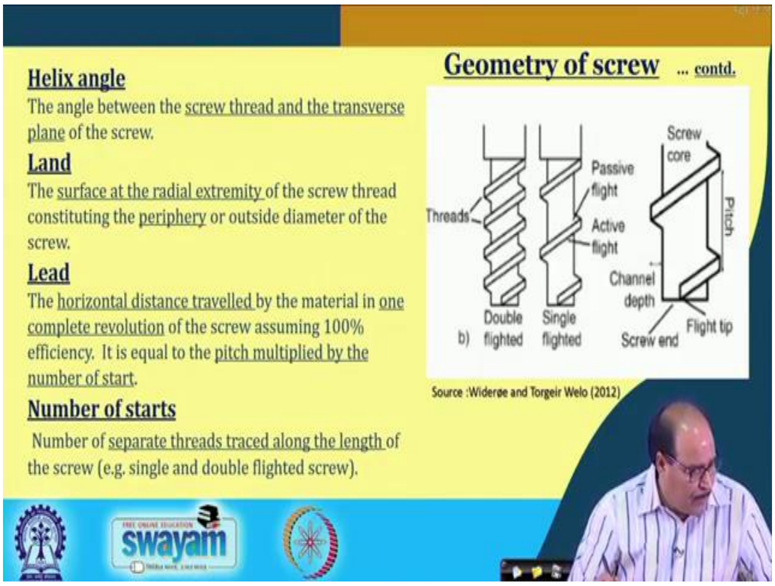
   It is the perpendicular distance from the top of the screw thread to the root surface.

3. **Pitch**

   It is the horizontal distance of the corresponding points of the two successive lands.

4. **Screw root**

   It is the continuous central shaft, usually of cylindrical or conical shape.



5. **Helix angle**

   It is the angle between the screw thread and the transverse plane of the screw.

6. **Land**

   It is the surface at the radial extremity of the screw thread constituting the periphery or outside diameter of the screw.

7. **Lead**

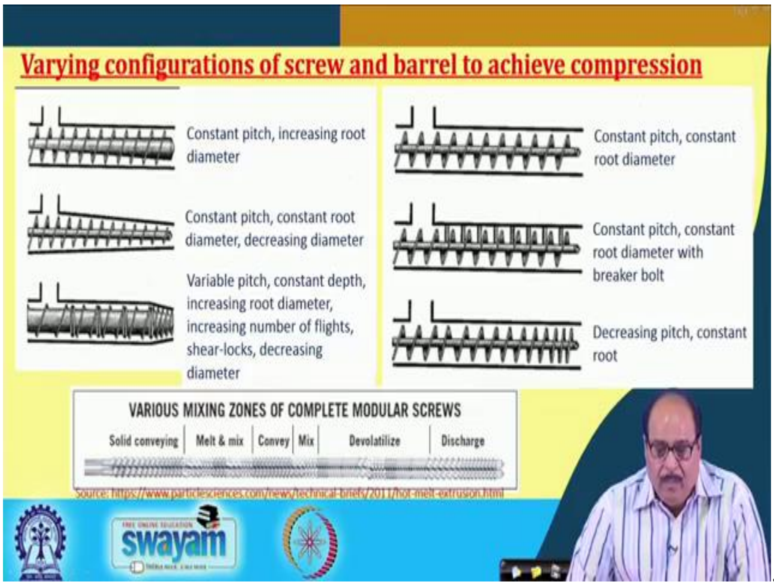
   It is the horizontal distance travelled by the material in one complete revolution of the screw assuming 100% efficiency. It is equal to the pitch multiplied by the number of start.

8. **Number of starts**

   It refers the number of separate threads traced along the length of the screw (e.g. single and double flighted screw).

Screw design variables

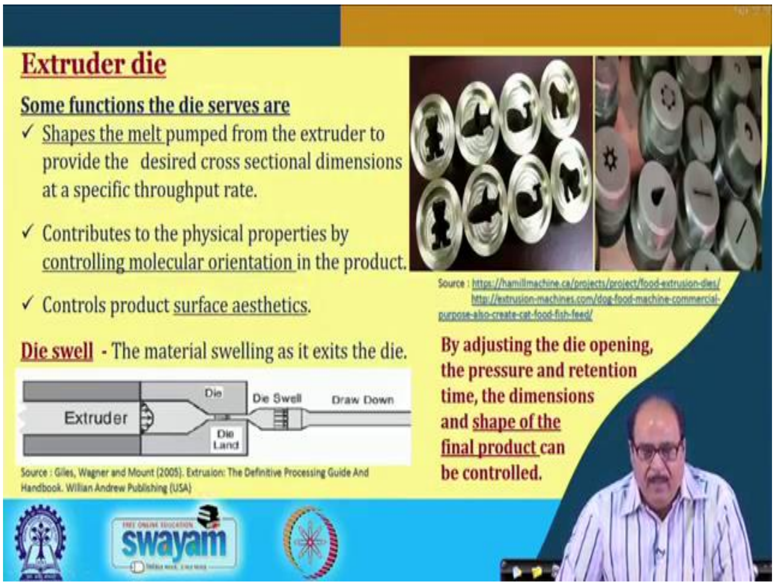
Variable	Definition	Effect
L/D ratio	Ratio of the flighted length of the screw to its outside diameter	Larger the L/D ratio • More shear heat can be uniformly generated. • Greater opportunity for homogenous mixing. • Greater residence time.
Compression ratio	Ratio of channel volume in the feeding zone to the channel volume in metering zone	Higher the compression ratio • Greater shear heat imparted to the material. • Uniform heat distribution. • Potential creating stresses in the material.
Helix angle	Angle of screw flight relative to the plane perpendicular to the screw axis	A change to a smaller helix angle, hence more flight turns per diameter • Reduces the axial melting length. • Conveys stiffer materials with greater ease (and less torque). • Reduces the rate at which material is conveyed.



Varying configurations of screw and barrel to achieve compression

There are different configurations of screw and the barrel present in the commercial extruders and accordingly it gives the desired compression (See Figure). The list of configuration is given below-

1. Constant pitch, increasing root diameter
2. Constant pitch, constant root diameter, decreasing diameter
3. Variable pitch, constant depth, increasing root diameter, increasing number of flights, shear-locks, decreasing diameter
4. Constant pitch, constant root diameter
5. Constant pitch, constant root diameter with breaker bolt
6. Decreasing pitch, constant root



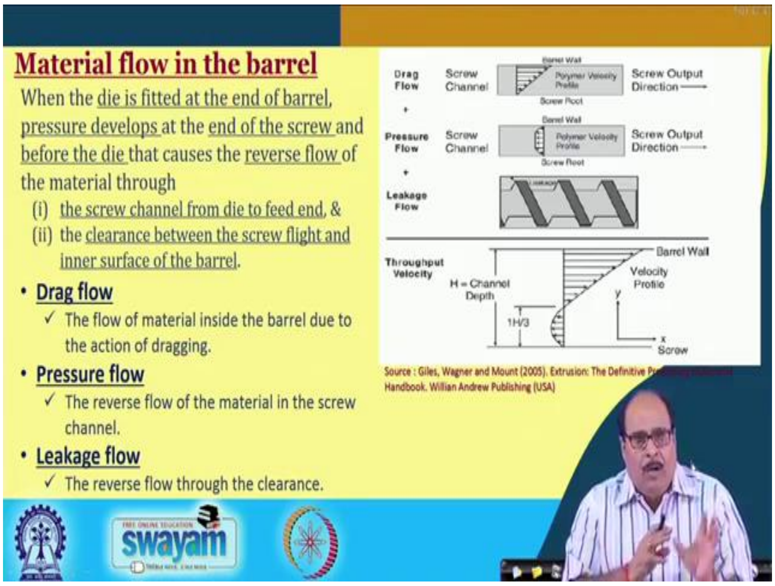
Extruder die

Another very important component of the extruder machine is the extruder die. Different types of extruder die can give products of different size, shapes, etc. By adjusting the die opening, the pressure and retention time, the dimensions and shape of the final product can be controlled.

Some functions the die serves are

- ✓ Shapes the melt pumped from the extruder to provide the desired cross sectional dimensions at a specific throughput rate.
- ✓ Contributes to the physical properties by controlling molecular orientation in the product.
- ✓ Controls product surface aesthetics.

Die swell **-** The material swelling as it exits the die.



Material flow in the barrel

When the die is fitted at the end of barrel, pressure develops at the end of the screw and before the die that causes the reverse flow of the material through

(i) the screw channel from die to feed end, &

(ii) the clearance between the screw flight and inner surface of the barrel.

1. **Drag flow**

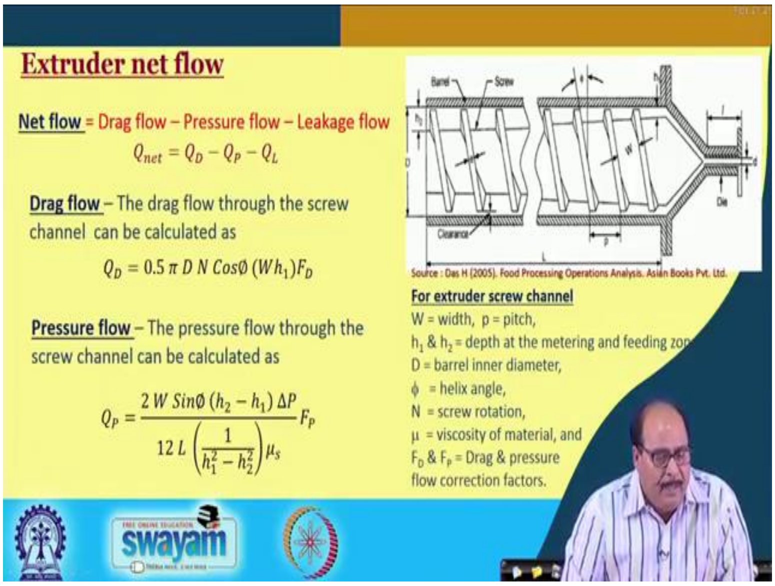
   It is the flow of material inside the barrel due to the action of dragging.

2. **Pressure flow**

   It is the reverse flow of the material in the screw channel.

3. **Leakage flow**

   It is the reverse flow through the clearance.



Extruder net flow

The extruder net flow through the extruder is given by the equation

Net flow = Drag flow – Pressure flow – Leakage flow

$$Q_{net} = Q_D - Q_P - Q_L$$

Drag flow – The drag flow through the screw channel can be calculated as

$$Q_D = 0.5\,\pi\,D\,N\,Cos\emptyset\,(Wh_1)F_D$$

Pressure flow – The pressure flow through the screw channel can be calculated as

$$Q_P = \frac{2\,W\,Sin\emptyset\,(h_2 - h_1)\,\Delta P}{12\,L\left(\frac{1}{h_1^2 - h_2^2}\right)\mu_s} F_P$$

Where, W is width of screw channel,

p is pitch of the screw,

h_1 & h_2 are depths at the metering and feeding zone, respectively,

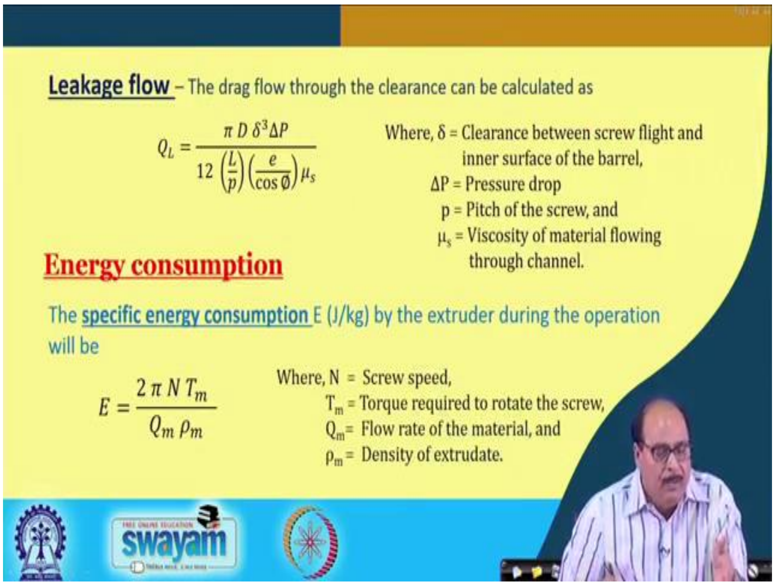
D is barrel inner diameter,

ϕ is helix angle,

N is screw rotation,

μ is viscosity of material, and

F_D & F_P are drag & pressure flow correction factors, respectively.



Leakage flow – The drag flow through the clearance can be calculated as

$$Q_L = \frac{\pi\, D\, \delta^3 \Delta P}{12\left(\frac{L}{p}\right)\left(\frac{e}{\cos \emptyset}\right)\mu_s}$$

Where, δ is clearance between screw flight and inner surface of the barrel,

ΔP is pressure drop

P is pitch of the screw, and

μ_s is viscosity of material flowing through channel.

Energy consumption

The specific energy consumption E (J/kg) by the extruder during the operation will be

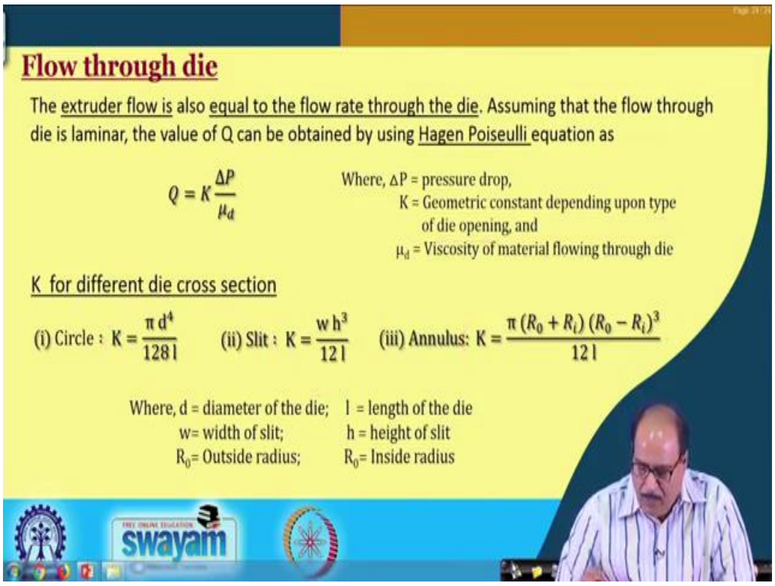
$$E = \frac{2\,\pi\, N\, T_m}{Q_m\, \rho_m}$$

Where, N is the screw speed,

T_m is the torque required to rotate the screw,

Q_m is the flow rate of the material, and

ρ_m is the density of extrudate.



Flow through die

The extruder flow is also equal to the flow rate through the die. Assuming that the flow through die is laminar, the value of Q can be obtained by using Hagen Poiseulli equation as

$$Q = K\frac{\Delta P}{\mu_d}$$

Where, ΔP is a pressure drop,

K is a Geometric constant depending upon type of die opening, and

μ_d is the viscosity of material flowing through die

K for different die cross section

(i) Circle : $K = \frac{\pi d^4}{128 l}$

(ii) Slit : $K = \frac{w h^3}{12 l}$

(iii) Annulus: $K = \frac{\pi (R_0 + R_i)(R_0 - R_i)^3}{12 l}$

Where, d is the diameter of the die;

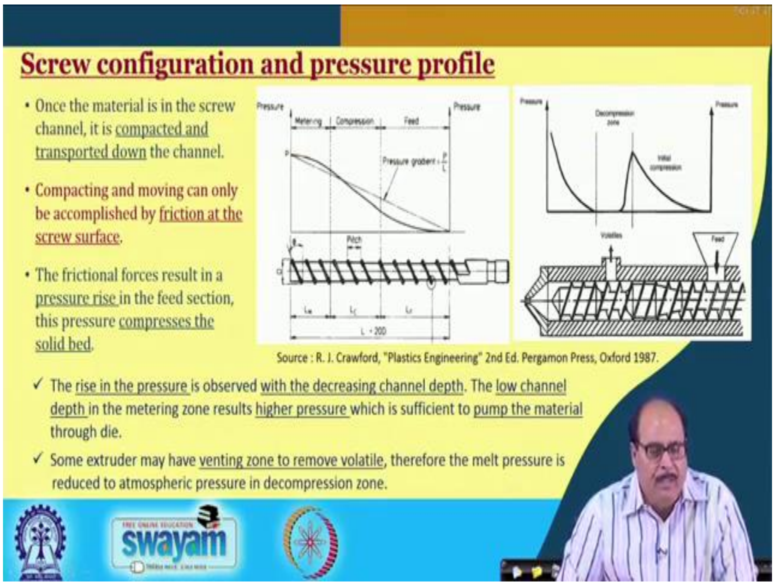
l is the length of the die

w is the width of slit;

h is the height of slit

R_0 is the Outside radius;

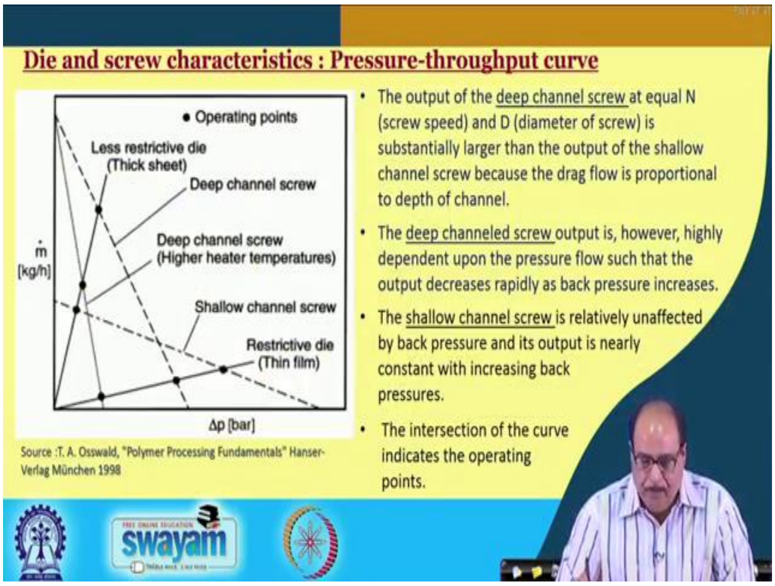
R_0 is the Inside radius



Screw configuration and pressure profile

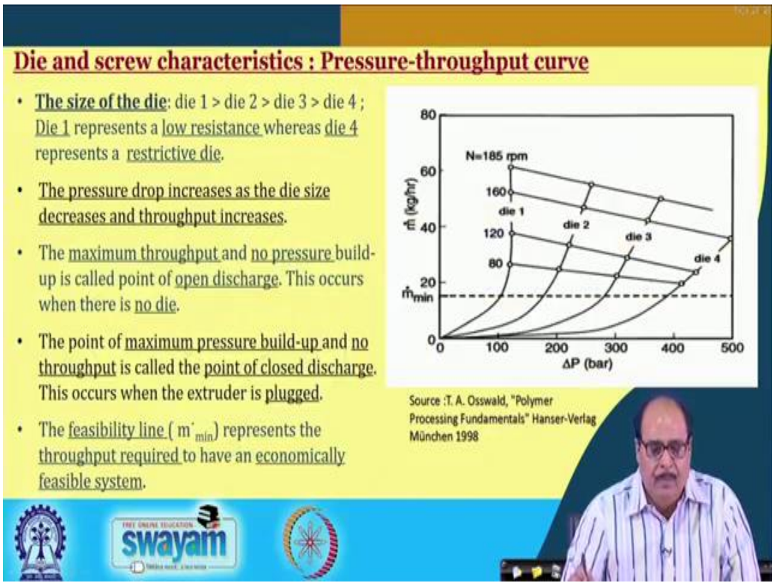
The screw configuration affects the pressure profile inside the barrel (see figures). Once the material is in the screw channel, it is compacted and transported down the channel. Compacting and moving can only be accomplished by friction at the screw surface. The frictional forces result in a pressure rise in the feed section, this pressure compresses the solid bed.

The rise in the pressure is observed with the decreasing channel depth. The low channel depth in the metering zone results in higher pressure which is sufficient to pump the material through die. Some extruder may have venting zone to remove volatile, therefore the melt pressure is reduced to atmospheric pressure in decompression zone.



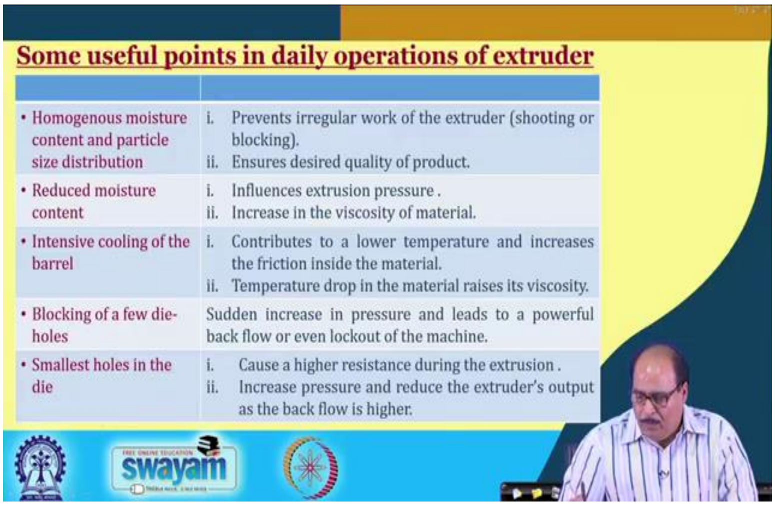
Die and screw characteristics: Pressure-throughput curve

Die and screw characteristics are explained by the graphical plot of the output/throughput versus pressure drop across the extruder. The output of the deep channel screw at equal N (screw speed) and D (diameter of screw) is substantially larger than the output of the shallow channel screw because the drag flow is proportional to depth of channel. The deep channeled screw output is, however, highly dependent upon the pressure flow such that the output decreases rapidly as back pressure increases. The shallow channel screw is relatively unaffected by back pressure and its output is nearly constant with increasing back pressures. The intersection of the curve indicates the operating points.



Die and screw characteristics: Pressure-throughput curve

- **If the size of the die**: die 1 > die 2 > die 3 > die 4 , then Die 1 represents a low resistance whereas die 4 represents a restrictive die.
- The pressure drop increases as the die size decreases and throughput increases.
- The maximum throughput and no pressure build- up is called point of open discharge. This occurs when there is no die.
- The point of maximum pressure build-up and no throughput is called the point of closed discharge. This occurs when the extruder is plugged.
- The feasibility line ($\dot{m}_{min}$) represents the throughput required to have an economically feasible system.



Some useful points in daily operations of extruder

• Homogenous moisture content and particle size distribution	i. Prevents irregular work of the extruder (shooting or blocking). ii. Ensures desired quality of product.
• Reduced moisture content	i. Influences extrusion pressure. ii. Increase in the viscosity of material.
• Intensive cooling of the barrel	i. Contributes to a lower temperature and increases the friction inside the material. ii. Temperature drop in the material raises its viscosity.
• Blocking of a few die-holes	Sudden increase in pressure and leads to a powerful back flow or even lockout of the machine.
• Smallest holes in the die	i. Cause a higher resistance during the extrusion . ii. Increase pressure and reduce the extruder’s output as the back flow is higher.