Extrusion

PFE -503

Extrusion technology

- High temperature short time (HTST) process
- Become well-known for continuous manufacture of new and traditional products.
- 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

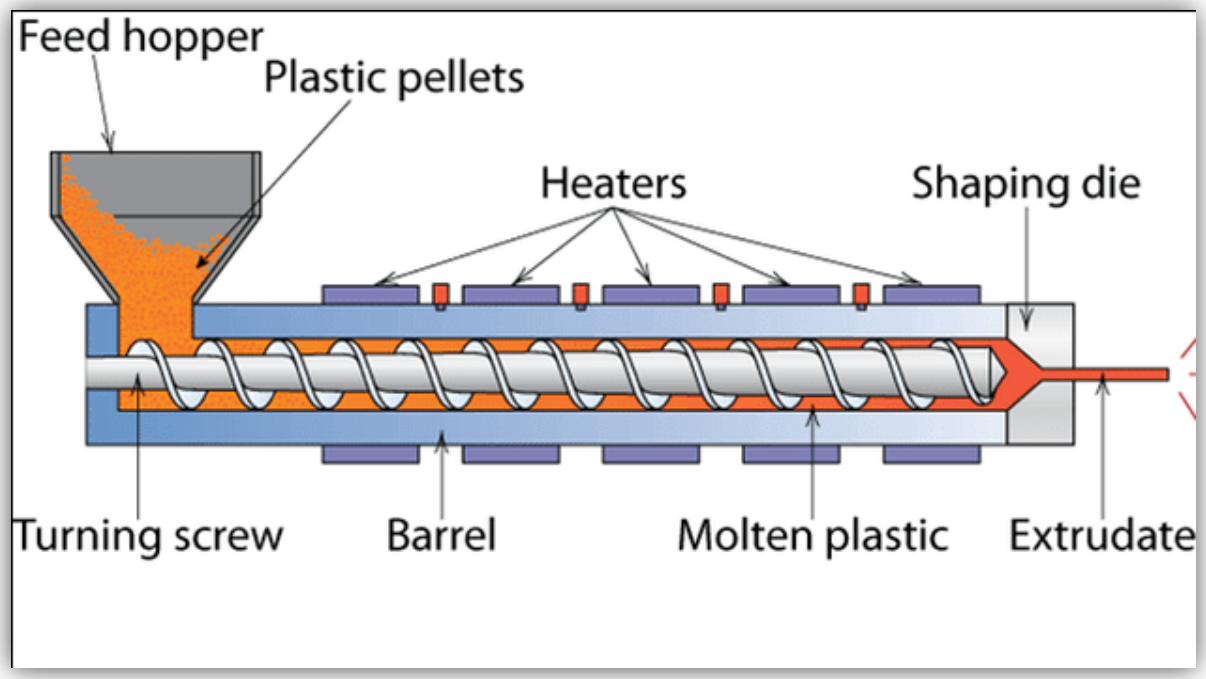
Extrusion cooking involves high temperature applied for a short time retaining many heat sensitive components of food.

Environmentally friendly

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

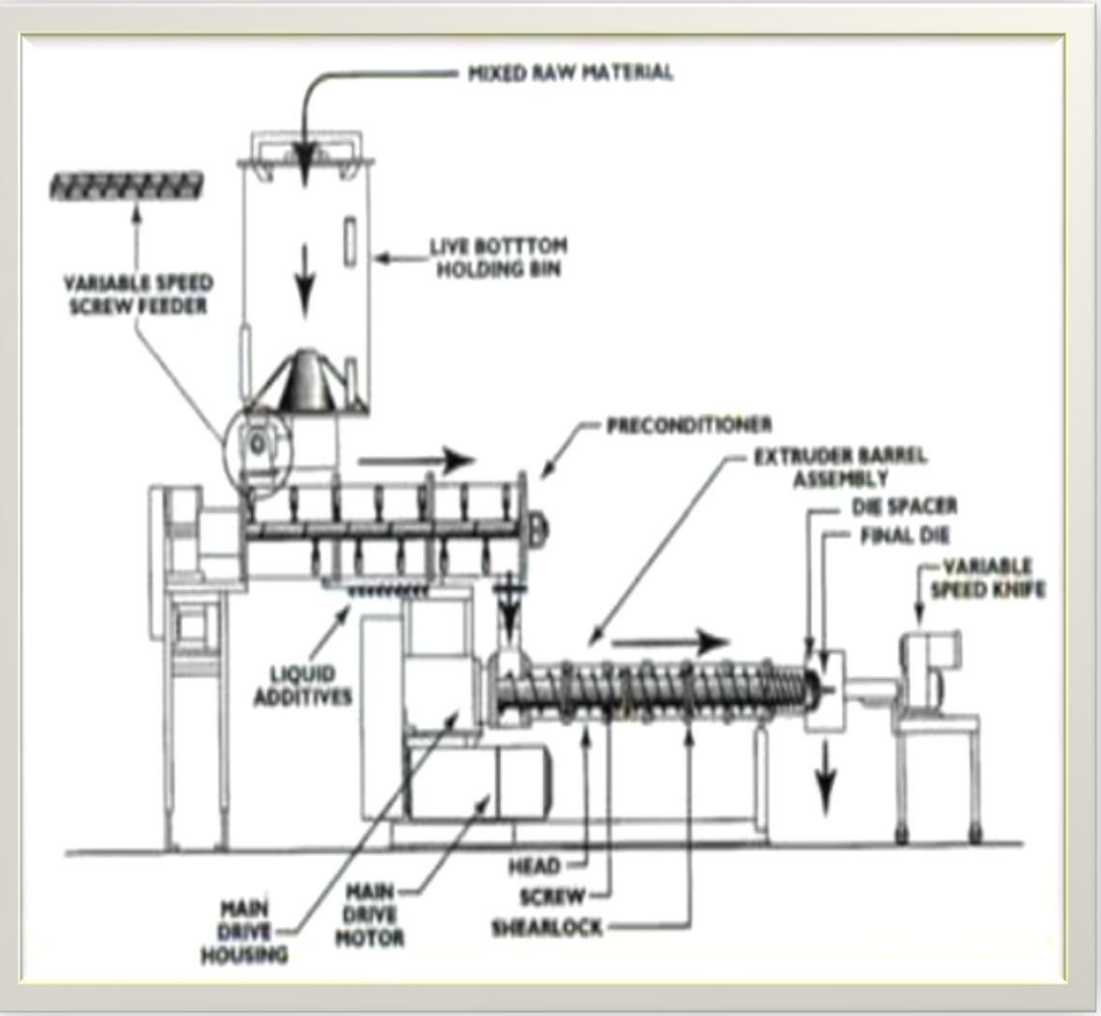
Extruder

- 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.



This extruder can be considered a screw reactor for physical, chemical and biochemical transformations of the materials.

General view of an extruder system

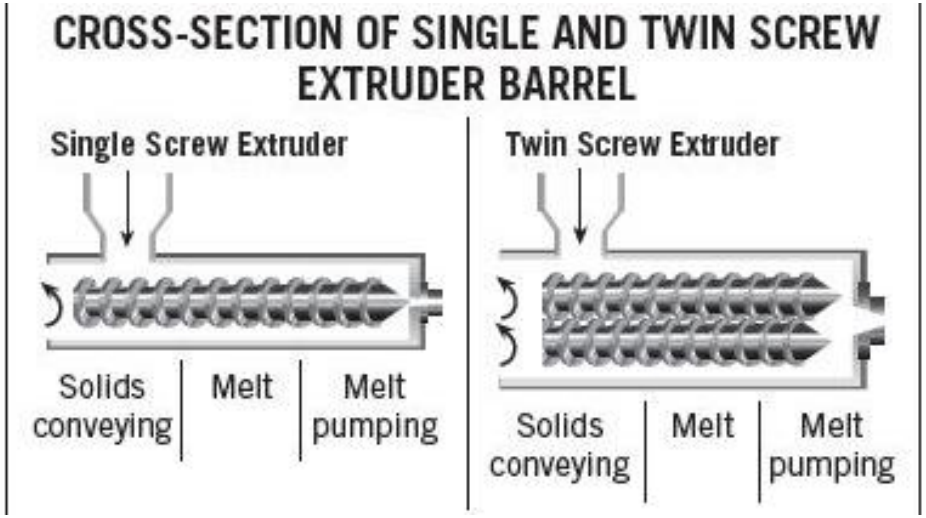


Extruder system consists of

- variable screw feeder
- holding bin
- pre-conditioner
- extrusion barrel assembly
- die head assembly

Types of extruder

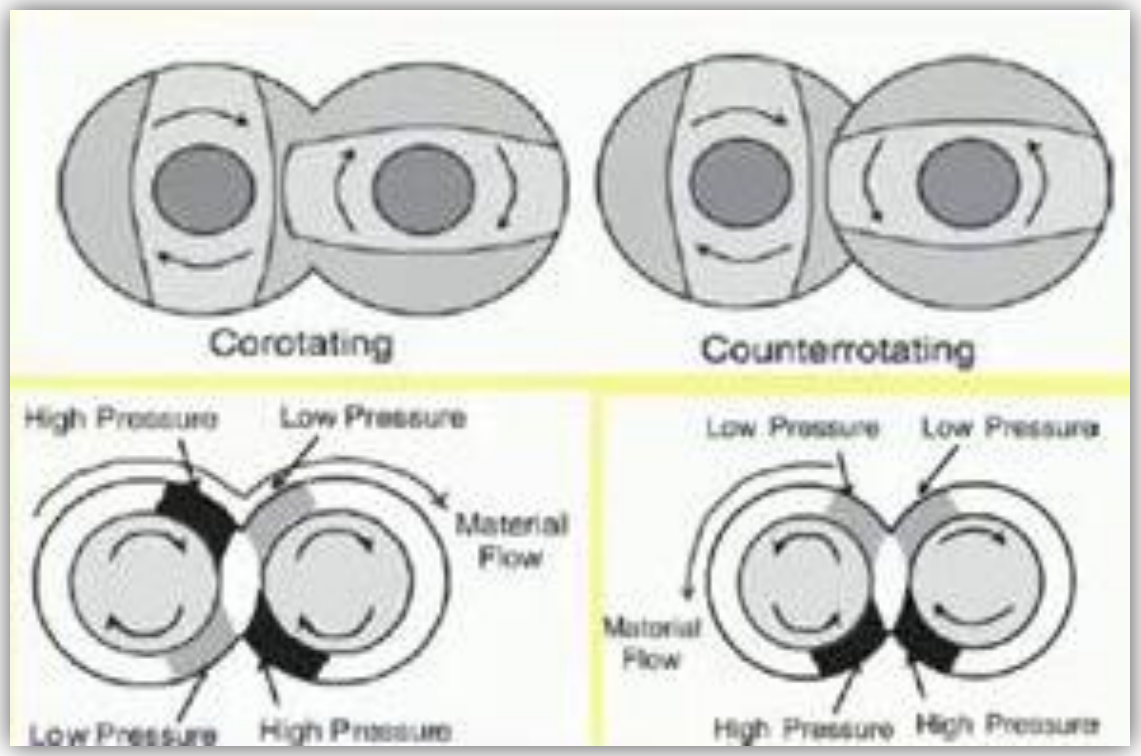
Two types i.e. single screw extruder, and twin screw extruder



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

(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)



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

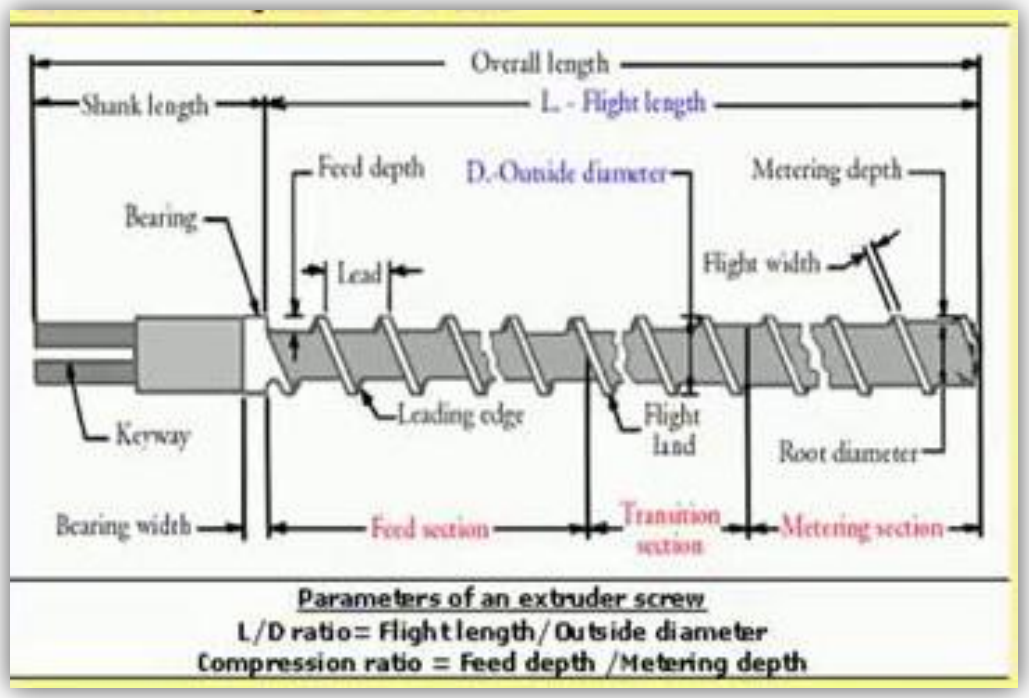
2. Kneading zone

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

Geometry of screw



Parameters of an extruder screw

L/D ratio = Flight length / Outside diameter

Compression ratio = Feed depth / Metering depth

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

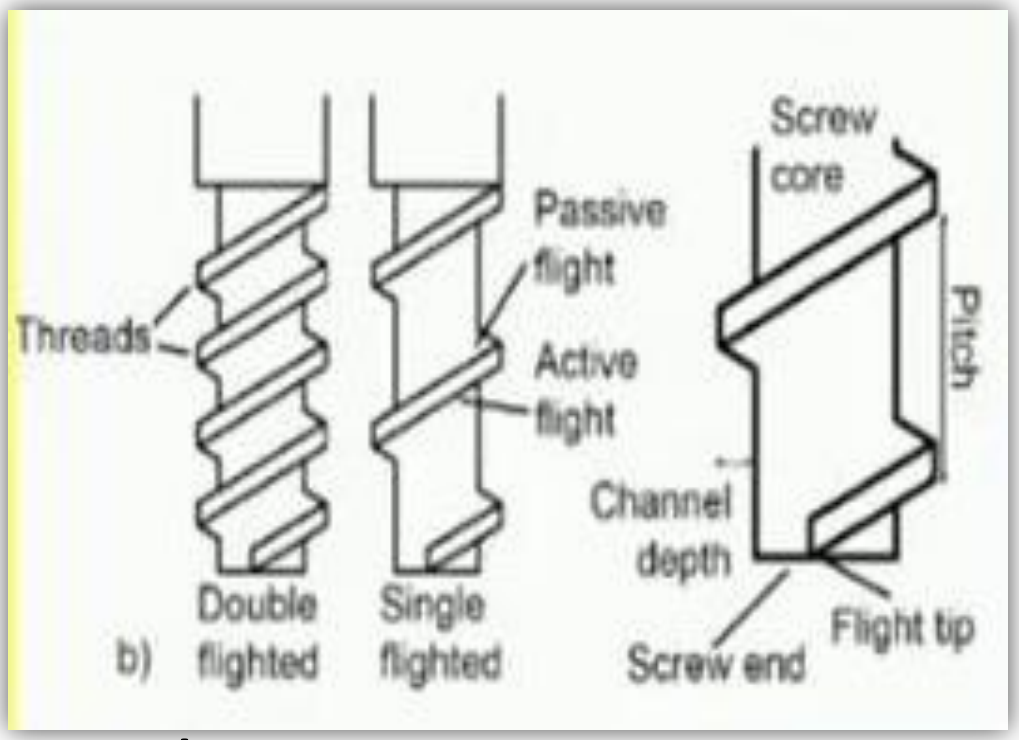
It is the perpendicular distance from the top of the screw thread to the root surface.

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.

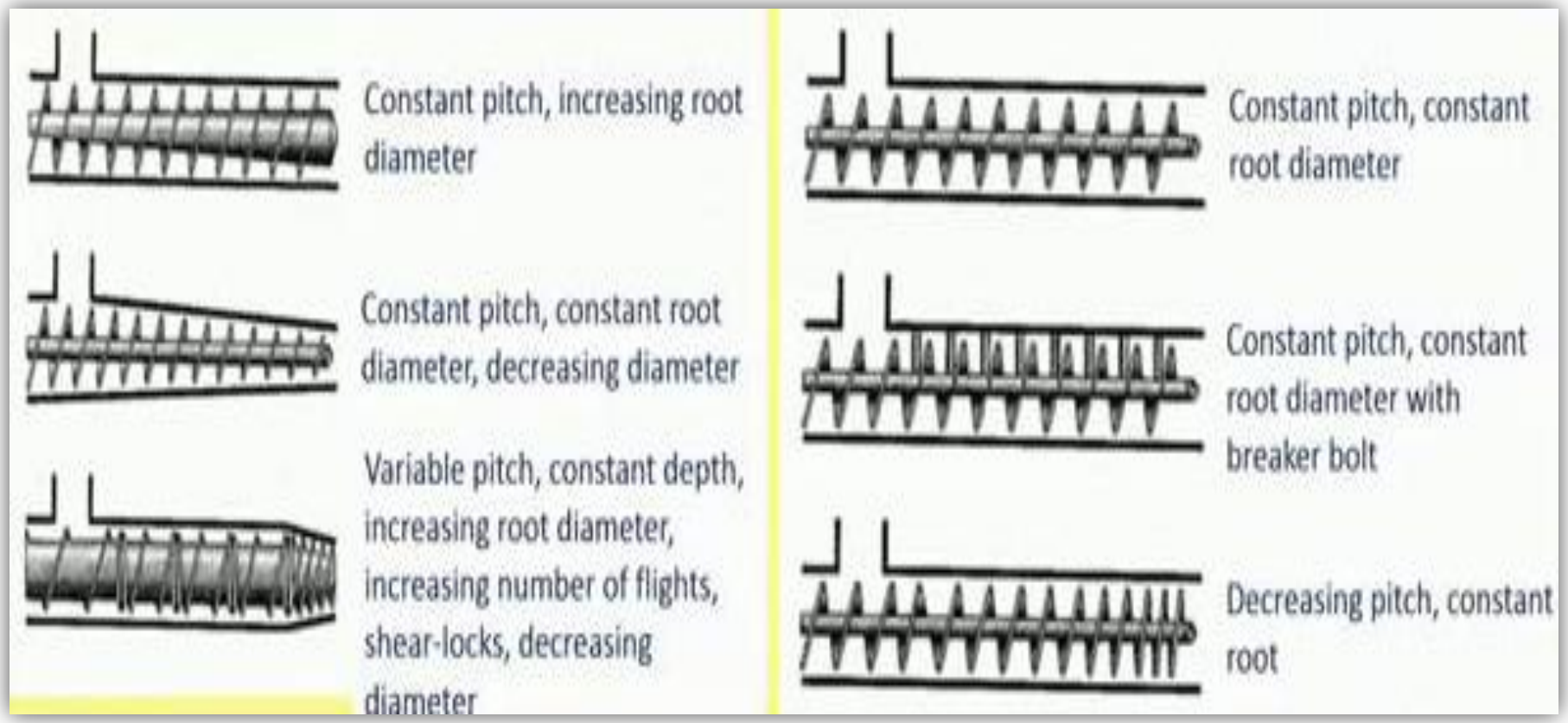
8. Number of starts

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. • Greateropportunity 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 greaterease (and less torque). •Reduces the rate at which material is conveyed.

Varying configurations of screw and barrel to achieve compression



Extruder die

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

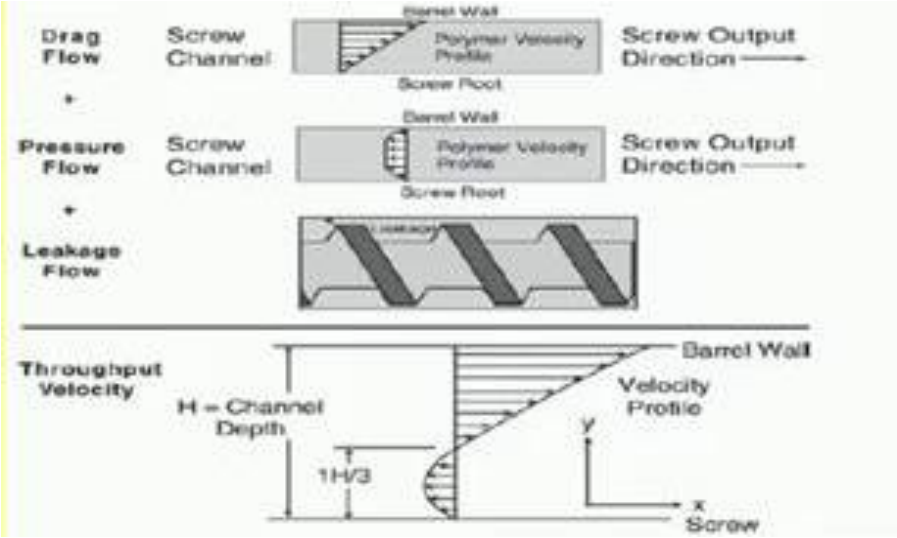
- Different types of extruder die can give products of different size, shapes, etc. By adjusting the die opening, the pressure and retention time, the dimensions and shape of the final product can be controlled.

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, and

(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

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

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

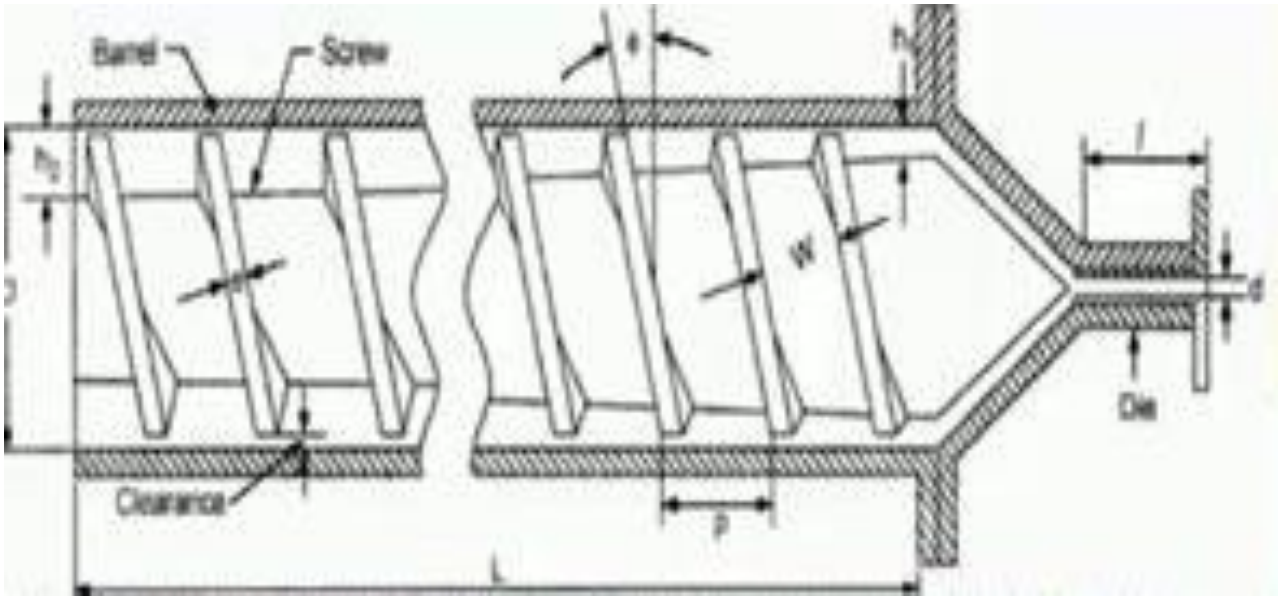
Where, W is width of screw channel,

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,



Where, W is width of screw channel,

p is pitch of the screw,

h1 & h2 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

FD & FP 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 = pressure drop,

K = Geometric constant depending upon type of die opening, and

μ_d = 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

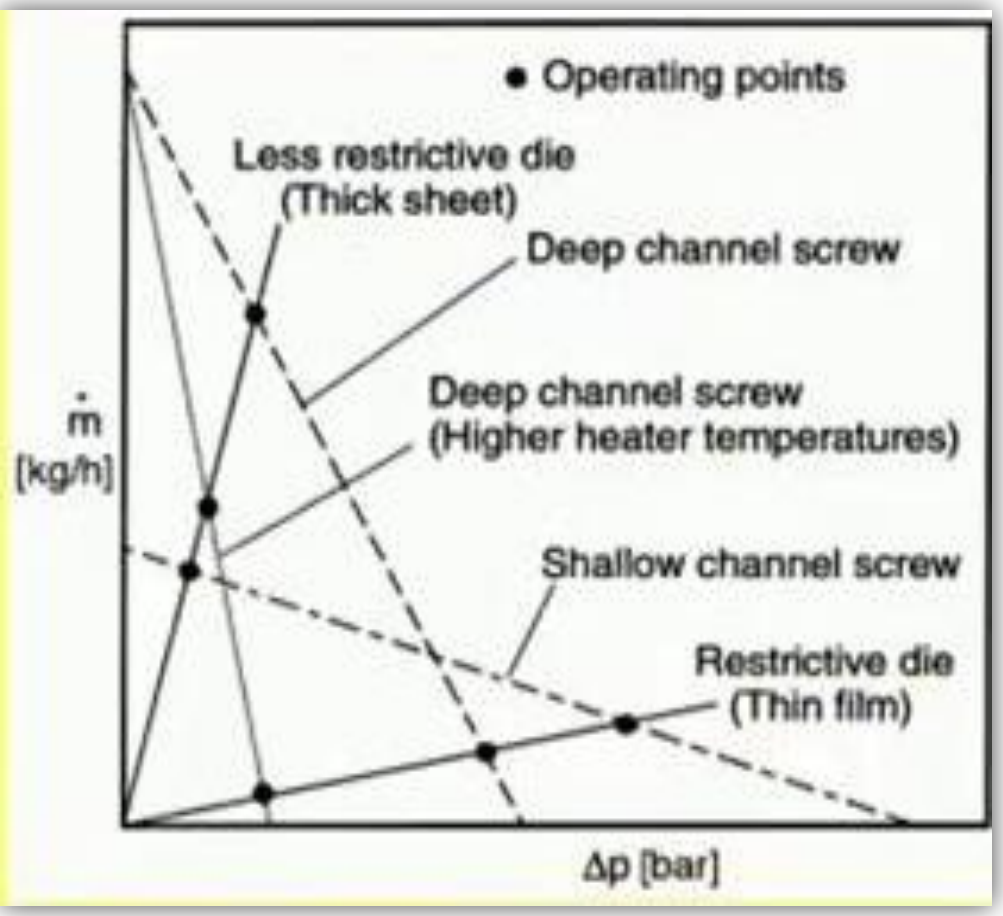
R_0 is the Outside radius;

R_0 is the Inside radius

Screw configuration and pressure profile

- 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.

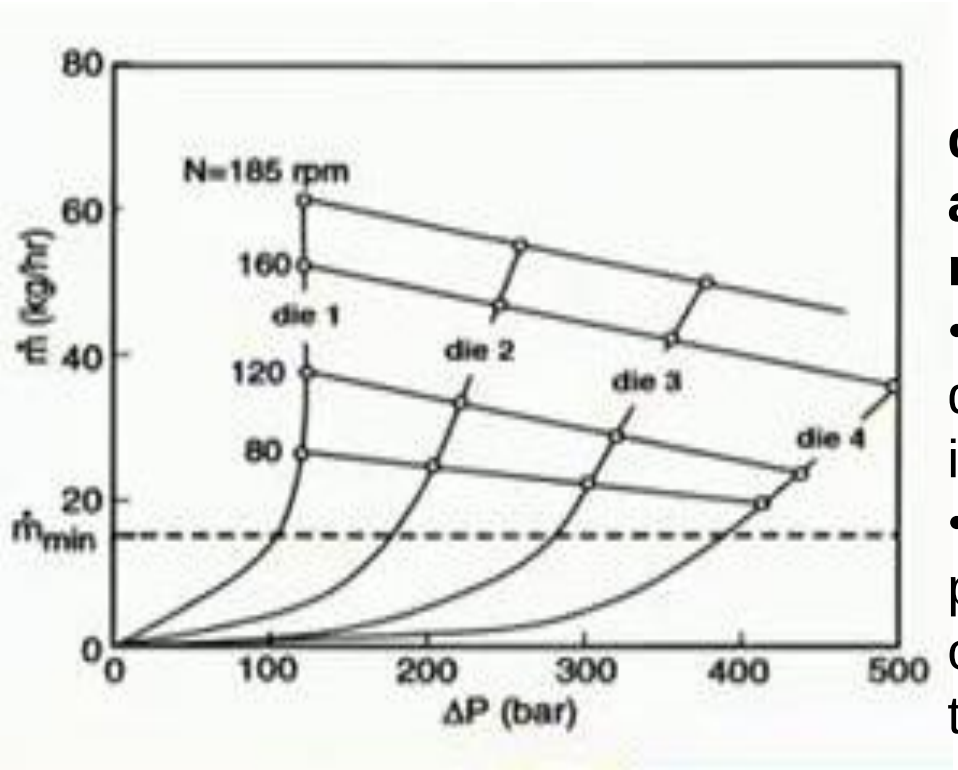
Die and screw characteristics: Pressure-throughput curve



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.

Extrusion Cooking

- Extrusion is a thermo mechanical process in which heat transfer, mass transfer, pressure changes and shear are combined to produce effects such as **cooking, sterilization, drying, melting, texturization, puffing, mixing, kneading, forming, etc.**

- Specifically designed die is used to shape the product such as pasta, noodles, rice analogues or variety of other products in a variety of shapes and sizes are produced using this technology.

extrusion process parameters

- Barrel temperature
- Die head temperature
- Extruder screw speed and
- Feed moisture content.

The product characteristics

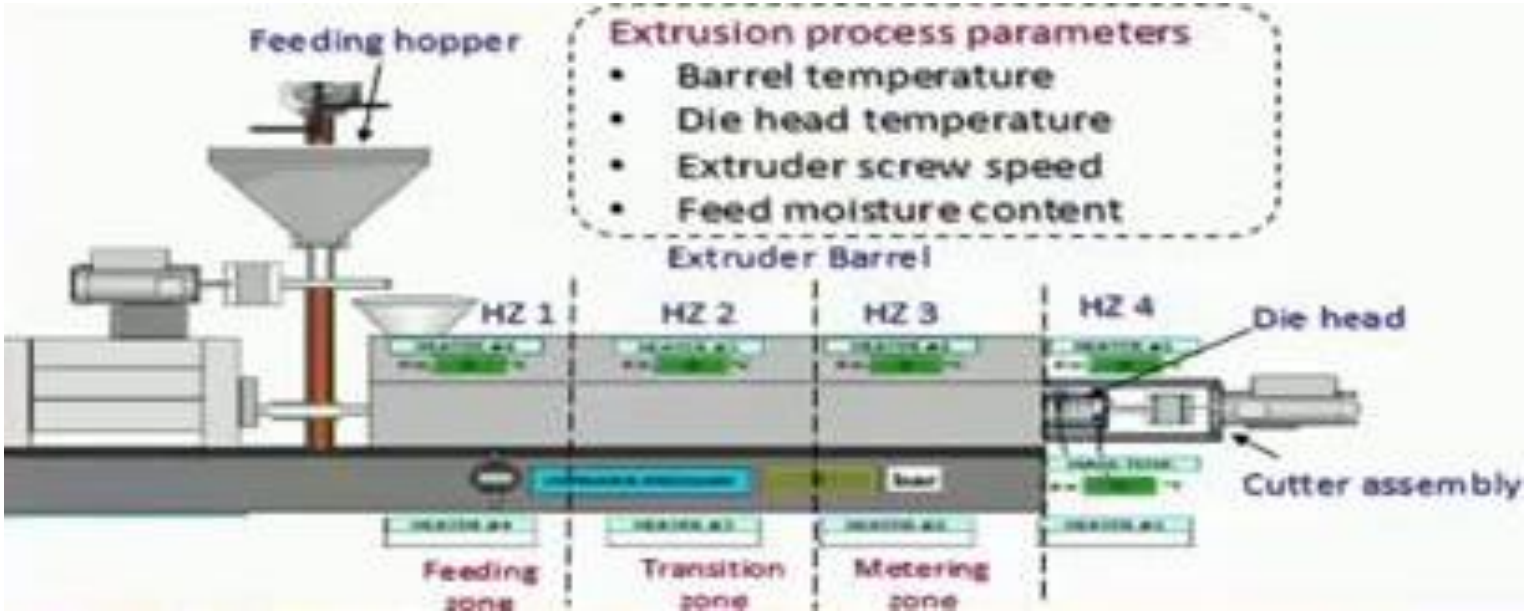
- Physicochemical properties,
- Functional properties,
- Textural characteristics and
- Cooking characteristics

extrusion system parameters

- Torque,
- Die pressure,
- Product temperature,
- Specific mechanical energies, etc.

The extruder have **three zones**

1. **feeding zone-** conveying the solid
2. **transition zone-** compaction, mixing and softening of the material takes place
3. M**etering zone-** melting, pressurizing and pumping of the melt to the die.



Raw Ingredients used in Extrusion Process

A. Structure Forming:

Maize: - Medium sized granuals (5-20µm)

- Average protein level (6-10%)
- Define flavor and yellow colour
- Expands well

Wheat: - Medium sized granuals (20-40 µm)

- Higher protein level (8-15%)
- Expands well
- Mild flavor
- White to off white in colour

Rice: - Small, tightly packed starch granules (2-8µ)

- Hydrate slowly and gelatinize
- Average Protein level (6-8%)]
- Bland flavor and white colour
- Expands well

Potato:- Large granules (60-100µm)

- High starch level (80-85%)
- Define flavour
- Gold to light browen colour
- Expands well but sticky
- Excellent binder

Oats: - Large content of fiber

- Highest content of lysine as compared to other cereal

B. Fillers:

- Fillers are most frequently protein fractions of oilseeds and the cereal grains which are added to the main ingredients.
- They improve the flexibility of the dough after hydration during mass plasticization inside the extruder.
- They reduce the swelling of starch during the mass forcing through the die and also reduce the size of air bubbles during the expansion of the extruder there by influencing the shape of the final products.

C. Plasticizers :

- The plasticizer in an extrusion cooked mixture are normally water, oil, fats and emulsifiers.
- They influence the flow of the material inside the extruder, reduce the degradation of starch and positively affect the quality and nutritional value of the product.

D. hydrocolloids:

- Used for providing thickness, thickening effect, stabilization and gelling effects for the improvement of the physical characteristics and textural properties of the end product.
- These hydrocolloids modify texture of the starch based food products as well as they influence the melting characteristics, gelatinization, fragmentation and retrograding processes.
- Hydrocolloids improve the thermal stability and provide lubrication during the extrusion process.

E. Emulsifier:

- The emulsifiers are the lipid fractions with higher melting temperature used as lubricants in the extruded product.
- They facilitate shear and formation of uniform surface structure, they protect processed mass against stickiness and thus making further treatment easier.
- The most commonly used emulsifiers in the products or in the extrusion technology are the soy lecithin and mono and diglyceride esters.

F. raising agents :

- It provide aeration of the mass and help to obtain the typical crispy and porous structure of the extrudates e.g. the baking powder.

G. Taste Component:

- Components like salt, sugar, sometimes some spices etc. are added to improve the taste in the extruder product.

Effect of extrusion processing conditions on the material characteristics

Role of Starch on Extrusion:

- Starch is one major component in the structure forming action which influences the product texture and other characteristics.
- So, during the extrusion processing the starch granules in presence of water undergo the process of gelatinization if the extrusion conditions are severe.
- In the rice granules how the starch looks like when gets gelatinized on coming in contact with the water and heat which is there inside the screw barrel

- Depending upon the conditions of temperature and pressure present inside the barrel, the starch granules get damaged by the shear forces etc.
- It may undergo dextrinization and in fact this dextrinized starch sometime gives the sweeter taste because these dextrins. They have the intermediate characteristics i.e. less sweeter than glucose, more sweeter than the starch.
- So, these high shear conditions are necessary in order to maximize the conversion of starch into glucose, so that the material gets the better sensory characteristics and other components.

- So, the loss of crystallinity can also be observed in the extruded product which is basically because of the gelatinization effect.
- The gelatinized starch, denatured protein and the cellulosic materials etc. which might be there in the raw material decisively influence the product expansion ability after forcing them through the die.

- So, the starch is an important ingredient as far as the extruder products and their characteristics are concerned.
- They are used for density control and to provide strength in the material.
- They might result in the shelf life improvement, moisture uptake, improve the flavour, water holding capacity, fat binding capacity, and other functionalities.

Effect of extrusion processing condition of Protein:

- Denaturation during extrusion process .
- The forces which stabilise the tertiary structure and quaternary structure of the proteins are weakened by a combination of increased temperature and shear within the extruder barrel.
- All these forces in fact are responsible to keep the structure in its native form bounded by covalent linkages, sulphide linkages, etc.
- So, the individual protein molecule unfold and align themselves with the flow of the material towards the die.
- The exposure of hydrophobic residues such as phenylalanine and tyrosine, they reduce the solubility of the extruded protein in aqueous systems.

Effect of Lipids on Extrusion Processing

- extrusion of high fat materials is generally not advisable especially in the case of expanded product. The fat content should be kept low as low as possible.

- **The presence of lipid in the raw material causes**
  - decrease in the torque as the lipid **reduces slip within the barrel.**
  - There is **poor expansion** of the product because insufficient pressure is developed.
  - Lipid is released from the cells owing to the high temperature and physical disruption of the plants cell walls.

- Low lipid level rises less than 5 % in the material facilitate a steady extrusion and improve the texture

- The extrusion processes can prevent free fatty acid release by denaturing the hydrolytic enzyme

Effect of extrusion processing on vitamins

- The retention of vitamins in extrusion cooking decreases with increasing temperature, screw speed and specific energy input.
- It also decreases with decreasing moisture, feed rate and die diameter; if the die diameter decreases, the vitamin retention will decrease.
- Then depending on the vitamin concerned, considerable degradation can occur especially in the product with high sensory appeal.

- The usage of specific vitamin compounds or forms of application with improved stability, i.e. those vitamins which have better stability can be used.
- Some time addition of extra amounts of vitamins may be in the form of vitamin mineral premix can be added in the product to make up the losses.
- This addition can be done during extrusion or storage stage or even post extrusion either by dusting, enrobing, spraying, coating or filling together with other ingredients that can be applied.
- So, by this desired quantity of vitamins can be maintained.

Effects of extrusion process on minerals:

- Minerals are more heat stable and are not likely to become lost in the steam distillate at the die, however extrusion can improve the absorption of minerals by reducing other factors that inhibit absorption.
- Mineral absorption could be affected by the phytate, polyphenols like tannins etc. and fibre components. So, cellulose, lignin and some hemicelluloses affect the mobility of these minerals in the gastrointestinal tract and interfere with their absorption while tannins might be insoluble complex might form in soluble complexes with divalent ions in the gastrointestinal tract.

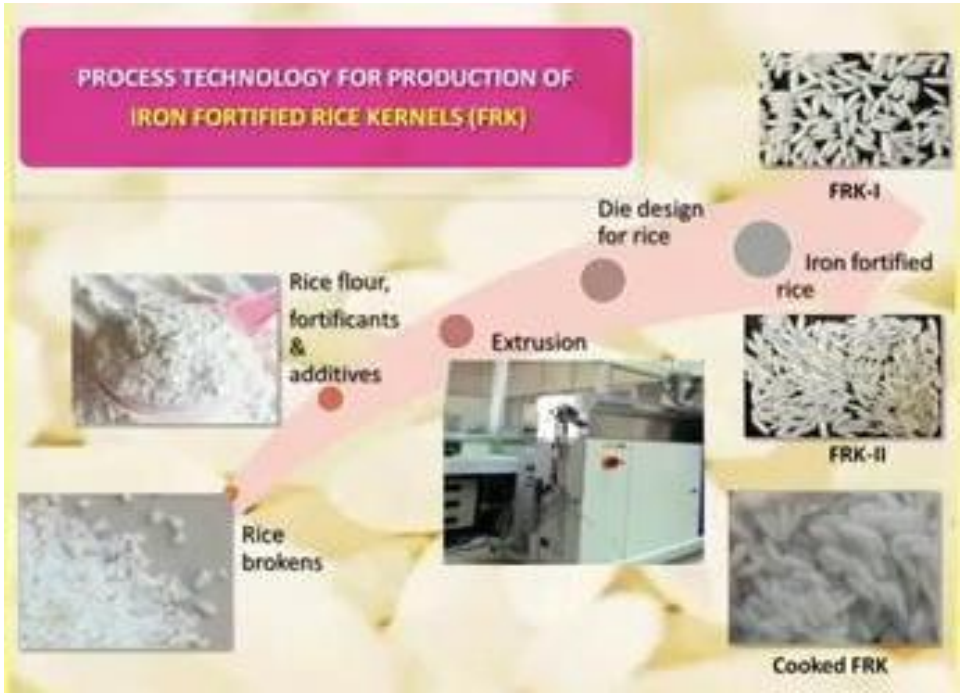
- So, the extrusion hydrolyses the phytates, decomposes the polyphenols, reorganizes the fiber components and changes chelating properties and this explains the higher availability of the mineral after extrusion processing particularly after high temperature extrusion.
- So, the availability of the mineral might be more in the extruder product as extrusion process improves the absorption characteristics of the minerals.

Innovative Extruded Product:

- fortified rice kernels
- essential amino acid balanced nutri dal,
- ready to eat snacks (may be from the millets etc.)
- sweet potato extrudates
- chlorella fortified pasta
- fortified rice noodles,

Most of these products are in ready to eat form; frying and other things might not be required.

Fortified rice kernels (FRK):



These are made by using the broken rice. Broken rice from the rice mill is taken and converted into flour. The conditioned rice flour is added with the fortificants like iron, folic acid and vitamin B12 in appropriate quantity as per the guidelines set by Food Safety and Standards Authority of India.

The extruder is designed and developed indigenously for this purpose and the rice die has been designed. The mix is forced through the extruder and the fortified rice kernels are made using this extrusion technology.

Essential amino acid balance nutri dal:

- Made with broken dal (by product of dal milling industry)
- Improved nutrient delivery like balanced amino acid, reduces antinutrient, requiredless time to cook

Gluten Free Pasta

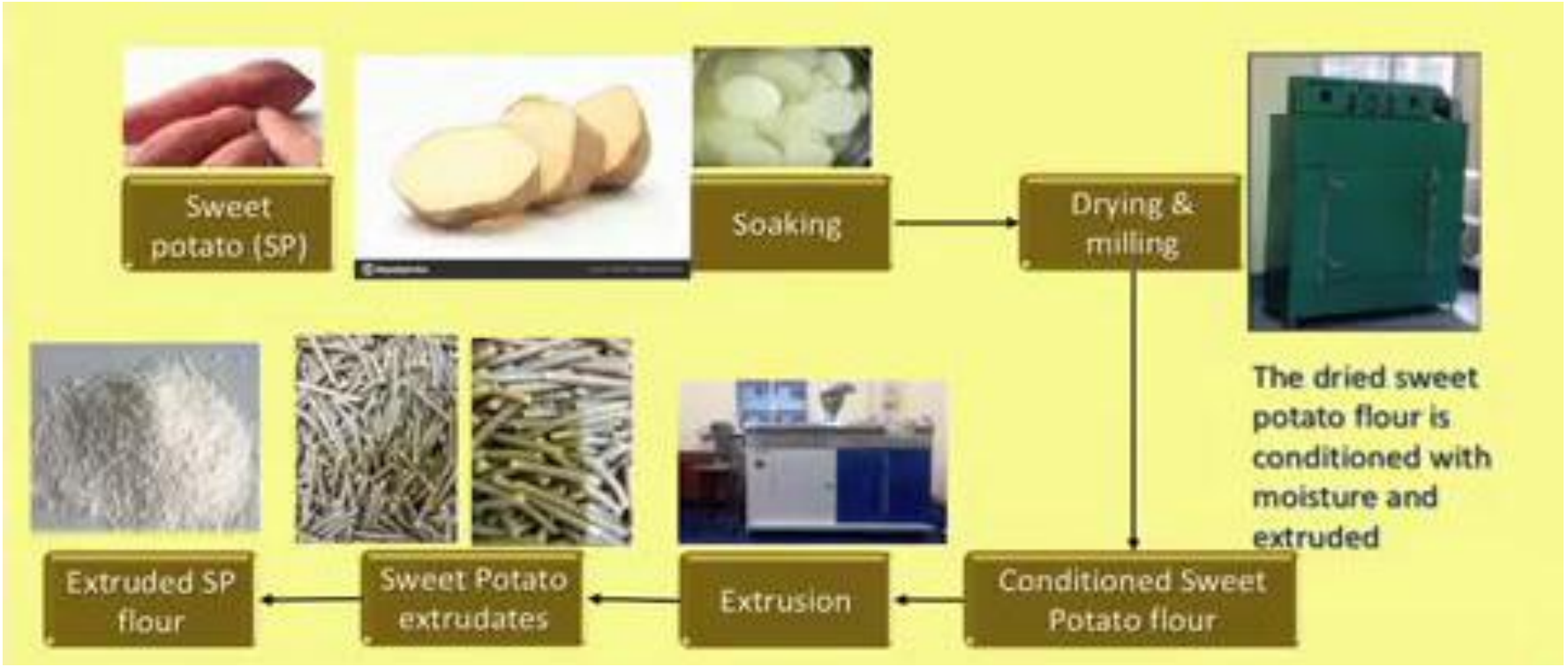
- For people suffering through celiac disease

Fortified Rice Noodles:

- Fortified by micronutrients like iron, vitamin B12 and folic acid.

Nutrient	Rice Noodles
Iron (mg/100g)	4.25
Folic acid (µg/100g)	12.5
Vitamin B_{12} (µg/100g)	0.12

Sweet Potato Flour



• It results in the significant reduction of the trypsin inhibitor and improvement in the in-vitro digestibility.