## POLYMER PROCESSING

Whether we want to make a toy or fabricate a spacecraft, polymers would have some central role to play. But how does one convert a p^r into a broad spectrum of useful shapes & structures. The answer is p^r processing.

In a broad sense, p^r processing may be defined as an engineering speciality used to convert polymeric materials into useful end products. Most of available techniques now employed in p^r processing are basically refined versions of those used in ceramic or metal industry.

P^rs in their pure form, as obtained from the manufacturing plants after isolation & purification, are called 'virgin' p^rs or virgin resins. Barring a few (such as PE, PP, PS), virgin p^rs, as such, may not be goods for processing straightaway. Virgin PVC, for example, is a material of a horny texture & cannot be moulded without making it soft by the add^n of a plasticizer. Natural rubber similarly requires a vulcanising agent to render it moldable. Most p^rs are protected from thermal, oxidative & photo degradation by incorporating appropriate stabilizers. Many articles are obtained in attractive colours by adding suitable dyes & pigments to the p^ric material prior to its moulding. Lubricants & process aids are added to most of the p^rs to reduce friction & improve flow within processing machineries. Fillers are added to impart special properties & reduce the finished product cost.

### Processing Techniques

The very fact that p^ric materials are used in many forms such as rods, tubes, sheets, foams, coatings or adhesives and also as moulded and fabricated articles implies that there must be variety of ways in ~~to~~ which the compounded resins can be processed & converted into finished products.

A majority of the articles are either moulded or fabricated, while many others are made by casting liquid prepolymers into a mould & allowing them to cure or cross link. Fibres are made by spinning process.

About 50 years ago, there existed only a few processes for converting p^ric materials into finished products. Today, there are many processes & automatic machines for this purpose, the important ones being calendering, casting, compression moulding, injection moulding, extrusion moulding, blow moulding, cold forming, thermoforming, foaming, reinforcing, melt spinning, dry spinning & wet spinning. → these 3 used for making fibres from fibre forming materials

Polymeric materials < Thermoplastic / Thermosets.

Once thermoplastic mat. are moulded ~~under~~ or shaped under heat & pressure, they are required to be cooled much below their softening temp. before being released out of the mould as otherwise they may get destroyed. However —

... there is no need to cool the article before releasing

There are many processes – selection of a process depends
factors including
- Quantity & production rate
- Dimensional accuracy & surface finish
- Form & detail of the product
- Nature of material
- size of final product.

In general, plastic processing have three phases –
1. Heating – To soften or melt the plastic
2. shaping/forming – Under constraint of some kind
3. Cooling – So that it ~~remains~~ retains its shape.

Thermoplastics start as regular pellets or granules & can be remelted
Thermosetting materials start as liquids/syrups, often called resins, as
powders or partially cured products (preforms) which need heat for
the shaping phase. The shaping is accompanied by a chemical $r^n$,
which means that the material does not soften on ~~reh~~ reheating. The $r^n$
may be exothermic, in which case cooling is required.

**Calendering** – This process is employed to produce continuous films
& sheets. The main part of a calendering machine is a
set of highly polished metal rollers rotating in opposite directions
with provision for precise adjustment of the gap between them, so that
the sheet of ~~p~~ required thickness is produced. Compounded polymeric
material is fed between the rollers which are maintained at elevated
temperature & the sheet emerging from the rollers is cooled by passing
through cold rollers. PVC, PE, ABS & rubbers are ~~are~~ among the
main $p^{rs}$ which are usually calendered into sheets.

**Die casting** – It is a relatively low cost process which consists of
converting a liquid prepolymer to a solid object with a
desired shape. Sheets, tubes, ~~rods~~ rods in limited lengths. can be produced
by the casting process. In the simplest version, the prepolymer compounded
suitably with a curative or other ingredients is poured into a petridish
(die). The dish is then kept in oven at elevated temp. for a few hours to
complete ~~complete~~ the cure $r^n$. On cooling to room temp, the solid product is pulled
out of the petridish. Instead of a prepolymer & a curative, a mixture of
$m^r$, catalyst & other ingredients can be heated to the poly$^n$ temp & poured
into the die. Poly$^n$ is allowed to continue inside the die till the solid
product is formed. Acrylics, ~~etc~~ epoxies, polyesters, phenolics & urethanes
are suitable for die casting. Depending on the convenience & availability,
the dies for casting are made of plaster of paris, lead or glass.

**Rotational casting** – Hollow articles such as balls & dolls are produced
by this process. The compounded thermoplastic
material in fine powder form is taken in a hollow mould. The
apparatus has provision for rotating the mould simultaneously along
the primary ~~axis~~ & the secondary ~~axis~~ axis. After closing the mould, it
is heated & rotated. This distributes the molten plastic uniformly along
the entire surface of the inside cavity of the mould. After a while, the
mould, still under rotation, is chilled with cold water. Now, the molten plastic
material uniformly distributed cools down & solidifies in the shape of that surface.
The mould can now be opened & the product removed. Instead of thermoplastic
materials, a thermosetting type prepolymer & curative mixture can also be fed into the
mould in liquid form & curing done under rotation at an elevated temp, when the product is formed.

To a large extent PVC articles such as rain-boots, hollow balls or doll heads are made by rotational casting.

**Film casting** – A casting technique is also used to produce polymeric films. In this technique, the solution in an appropriate concentration of the p$^r$ in a suitable solvent is allowed to fall at a precalculated rate on an endless metallic belt of high finish moving at a constant speed. A continuous sheet of the p$^r$ solution is thus formed on the surface of the metallic belt. When the solvent is subsequently evaporated under controlled conditions, a thin film of the p$^r$ is formed on the surface of the belt. The film could be removed simply by stripping. Most of the commercially available varities of cellophane sheets & photographic films are prepared by this process.

**Compression moulding** – The compression moulding process is very widely used to produce articles from thermosetting materials.

The mould is made of two halves – the upper half (male part) & the lower half (female part). The lower half contains a cavity & the upper half has a projection which fits into the cavity when the mould is closed. The gap between the two halves gives the shape of moulded articles.

In compression moulding, the thermosetting material is subjected to heat & pressure in a single stroke, which is done by using a hydraulic press with heated platens. Moulding temp. & pressure can be as high as 200°C and 70 kg/cm², respectively. The actual temp. & pressure ~~can~~ depends on the rheological, thermal & other properties of the material to be moulded.

The compounded material is placed in the cavity of the mould so as to fully fill the cavity. As the mould closes down under pressure, the material is squeezed or compressed between the two halves & compacted to shape inside the cavity. The excess material flows out of the mould as a thin film, which is called "flash". Under the influence of heat, the compacted mass gets cured & hardened to shape. The mould can be opened while it is still hot to release the moulded product.

**Injection moulding** – The injection moulding process is best suited for producing articles made of thermoplastic materials. Here, the equipment cost is relatively high but its major attraction is high production rate.

In inj$^n$ moulding, a definite quantity of molten thermoplastic material is injected under pressure into a relatively cold mould where it is solidified ~~to~~ to the shape of the mould.

The process consists of feeding the compounded plastic material as granules, pellets or powder through the hopper at definite time intervals into the hot horizontal cylinder where it gets softened. Pressure is applied through a hydraulically driven piston to push the molten material through a cylinder into a mould fitted at the end of the cylinder. While moving through the hot zone of the cylinder, a device called "torpedo" helps spread the plastic material uniformly around the inside wall of the hot cylinder and thus ensures uniform heat distribution. The molten plastic material from the cylinder is then injected through a nozzle into the mould cavity.

The mould used, in its simplest form, is a two part system. One is a movable part & the other stationary. The stationary part is fixed to the end of the cylinder while the movable part can be opened or locked on to the stationary part. By using a mechanical locking device, the mould is properly held in position as the molten plastic material is injected under a pressure as high as 1500 kg/cm².

Further, the mould is preheated to an appropriate temperature as to eject the moulded article.

**Blow Moulding** – Most of the hollow plastic articles are produced by the blow moulding technique. Containers, soft drink bottles and numerous other hollow articles can be produced by this process. Thermoplastic materials such as PE, PC, PVC, PS, Nylon, PP, Acrylics, PET Acrylonitrile & ABS p^r can be blow moulded, however HDPE tops the list in terms of annual consumption.

A hot, softened thermoplastic tube, usually called "parison", is properly placed inside the two-piece hollow mould. When the two halves of the mould are closed, it pinches & closes one end of the parison & encloses a blowing pin at the other end. The parison is now blown by pressurising from within by blowing compressed air through the blowing pin. The hot parison is inflated like a balloon & goes on expanding until it comes in intimate contact with the relatively cold interior surface of the hollow mould. Under pressure, the parison ultimately assumes the shape of the hollow cavity of the mould. The mould is allowed to cool further & the rigid thermoplastic article formed is removed by opening the mould.

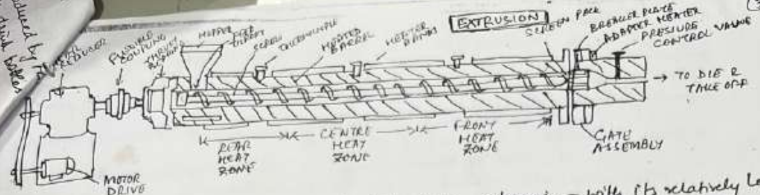
The parison needed for blow moulding can be made either by the injection or extrusion process, and the technique can accordingly be called injection BM or extrusion BM.

**Thermoforming** – It is a highly useful process for fabricating three dimensional articles from plastic sheets. Even some large products, such as submarine hulls are made of ABS sheets by thermoforming techniques.

The technique can be outlined as follows. The thermoplastic sheet is heated to its softening temp. The warm flexible sheet is then pressed into the female half of a matched metal die duly assisted by the male half. Now, the sheet assumes the required shape of the mould. On cooling, the shaped article becomes rigid & can be removed from the mould.

In a modified method, the hot plastic sheet is sucked into the cavity of the female mould under the influence of vacuum to give the desired shape. This method is called "vacuum thermoforming".

# EXTRUSION




As one of the basic processing techniques, extrusion – with its relatively low cost of melting, pressuring, delivering – dominates in the manufacture of continuous shapes such as rods, tubes, film, sheet, pipes etc.

For the simplest of single screw machine, which is the most common & popular type of extruder. The machine takes the plastic material in granular or powdered form. conveys it by the action of the screw & squeezes & heats it to form a molten stream, so that pressure is developed on the material & forces it through a die in the shape of die opening.

Extruders are also used to apply insulation & jacketing to wire & cable or to coat substrates such as paper, foil or cloth.

Although single screw extruders dominate the extrusion field, it is possible to use two or four screws. These multi screw extruders result in high conveying capacity at low screw speed, positive & controlled pumping rate over a wide range of temp., low frictional heat, low contact time in extruder, low motor power requirements. & the ability to feed normally difficult feeding materials like powders. Twin screw extruders find wide usage in PVC extrusion due to their low temp extrusion characteristics.

Another variant in extrusion process is the use of a ram instead of a screw to build up pressure & to force the molten plastic into the die, But they are used in a very limited applications, e.g. in handling some of the extremely tough thermoplastics like ultra-high mol wt. PE, & ~~high~~ + hard-to-process fluoro plastics like TFE. Ram type continuous flow extruders also find some use in extruding thermoset materials e.g. phenolics, melamines, ureas although thermoset are generally not considered for extrusion.

~~A newer type of extruder is screwless extruder.~~

## Single Screw Extruder Operation –

The plastic pellets or powder are fed from a feed hopper through the feed throat into the channel of a screw. The screw rotates in a barrel, which is heated or cooled to adjust or hold a particular melt temperature and serves almost as a pressure vessel to contain the operation, and while rotating, conveys the plastic forward for melting & delivery.

A drive motor provides the power for the controlled rotation of the screw while the thrust of the screw is taken up by a thrust bearing.

Heat is generally applied to the barrel by elec. heaters, whose temp. is measured by thermocouples. As the material moves along the screw, it is melted and forced through a breakerplate which often carries a screen pack. The function of the plate & screen is to reduce rotary motion of the melt and remove large particles. In some extruders, an extrusion valve is used to regulate the operating pressure of the extruders.

Finally the melt passes through an adaptor & into the die which determines the shape of the final product.

Usually, the extruder must be followed by some kind of a cooling system to remove heat sufficiently to ~~provide~~ solidify the final prod.

keeping it submerged so that the water cools the section. Small plates the shape of the finished extrusion are often used to hold the plastic passes through the water. These are called sizing plates. Depending on the of the finished extrusion part rollers, adjustable fingers or blocks of metal can be used for sizing.

Air cooling is similar to water cooling except that streams of air are blown against the extruded section.

Near the end of the extrusion line, there usually is some sort of a powered device, called a take-off, which functions in gripping the extrusion & pulling it through the cooling phase. The simplest device may be a pair of pinch rolls. Sometimes a single long belt or conveyor is used with counter-weighted rolls above to exert a gripping action. The whole purpose is to grip the piece hard enough to pull it through without crushing or distortion. The variation in take off speed is used to vary the draw down for precise control of section size.

~~Following extrusion, the extruded product must be reduced to its most useful form.~~

Extruder Nomenclature

In understanding the relation between the size & output of extruders, a common expression is the L/D ratio, which is defined as the length of the flighted part of the screw divided by the inside diameter (D) of the barrel. The L/D ratio is important, as, it defines the available surface area of the barrel which can be used for heat transfer and the length of the screw which will be available for the various functions of feeding, metering, devolatilization etc.

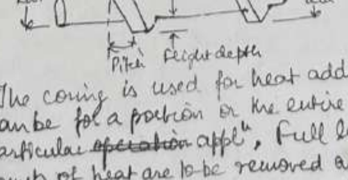
The ~~to~~ higher value of this ratio results in achieving higher outputs & better uniformity of the melt. Earlier this ratio was often under 15:1 whereas of late ratios of 28:1 have become common. & some sheet extrusion lines use ratios of 30:1 or 32:1.

The normal size specification used for extruders is based on the inside diameter expressed in inches. Diameters vary from 1 to 20 inches or more. The output for each rpm increases rapidly for increase in extruder diameter, assuming the screw dimensions are scaled in a consistent manner. e.g. a $4\frac{1}{2}$ inch extruder may deliver about $4\frac{1}{2}$ lb per hour per rpm, a 6 inch extruder about 9 lb/hr/rpm and a 9 inch extruder about 18 pph/rpm.

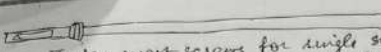
These outputs would change considerably for different screw designs, operating temperatures and ~~resins~~ plastic material.

Extruder Construction

In the design of the extruder, the screw plays a basic role. In a typical extruder, the screw consists of a steel cylinder which may be either solid or cored.




The coring is used for heat addition, or more often, heat removal. Coring can be for a portion or the entire length of the screw, depending on the particular ~~operation~~ appln. Full length coring is preferred where large amounts of heat are to be removed and a drop in melt temp. is desired. Coring into only the early portions of the screw is ~~done~~ used for those resins which tend to soften easily.



Today most screws for single screw machines are full flighted, i.e. they have turns over their entire lengths. These turns are usually made with a constant pitch, equal to the screw diameter. Most extruder screws are made of low-carbon alloy steel such as SAE 4140.

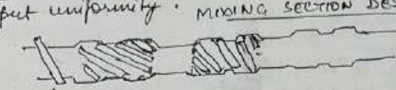
There are many variations possible in screw design to accommodate a wide range of plastics or appl^ns. leading to need of computerized screw design in which such variables as screw geometry, material characteristic, operating conditions etc. can be analyzed via mathematical models.

In practice, screw design can vary from continuous flight screw with constant pitch to more sophisticated designs that include flow disrupters or mixing sections. These mixer screws were developed to produce more thorough melt mixing & to balance heat distribution in the metering section of the screw prior to the time the melt enters the die.

~~Screw Zones~~ They have also found use in mixing dissimilar materials i.e. additive / resin combinations of dissimilar resins & in improving extruder output uniformity.

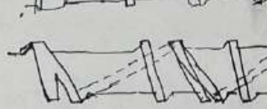
The tips of their flights are hardened to prevent wear, either by welding of an appropriate metal alloy, by flame hardening the flights or by nitriding the entire screw. Screws for vinyl p^rs are sometimes chromium plated for corrosion resistance & screws for saran (PVDC) polyvinylidene chloride ( $-\overset{H}{C}-\overset{Cl}{C}-$ ) ~~(CH2-CCl2)~~ are made of special nickel alloys.

MIXING SECTION DESIGNS

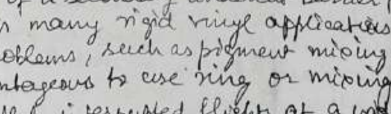


Parallel Interrupted Mixing Flights

MIXING PINS



RING BARRIER TYPE.



UNDERCUT SPIRAL BARRIER TYPE.

The use of a secondary undercut barrier flight for several turns is favoured in many rigid vinyl applications. For some special dispersion problems, such as pigment mixing during extrusion, it can be advantageous to use ring or mixing pins or sometimes many parallel interrupted flights at a wide pitch angle.

~~SR~~ SCREW ZONES – One of the basic parameters in screw design involves the ratio of lengths between the feed, transition & metering zones of the screw. Each has its own special role.

The feed section picks up the pellets, powder or beads & conveys them forward in the solid state. Generally, several flights of constant depth are provided to level out irregularities of feed. Because of the reduction in bulk is effected as the material is moved forward & plasticated, a compression is built into the screw. This also prevents occluded air from being carried forward with the resin.

The transition zone, between the deep flighted feed section & the shallower metering zone, builds up pressure & starts fluxing the plastic

The transition may be either gradual or abrupt depending on the ma
to be extruded.
The feed section usually has a higher capacity than the tra
& metering zones, so that sufficient material is supplied to these zones
zones. For many screw designs, feed depth is 3 to 5 times as deep as
the metering zones. This ratio of feed to metering section flight depth
is known as the depth or compression ratio.

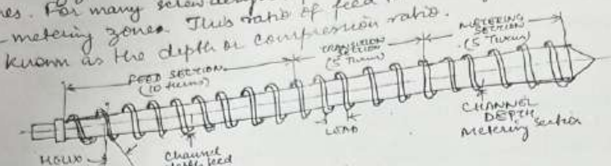



Fig: Basic parameters in screw design.

The resin should be fully melted into a reasonably uniform melt by the time it gets to the metering zone, as this zone ~~should~~ controls uniformity of output rate. For this good uniform feed rate is very important. One of the basic problem of the feed section is caused by pellets becoming prematurely tacky ~~with resultant~~ resulting in "bridging" and loss of feeding characteristic. This "bridging" problem can be reduced by suitable cooling of the feed hopper section. "Bridging" tends to become more severe with large extruder sizes, high screw speeds, low temp. softening resins and ineffective hopper cooling.

Higher feed efficiencies are achieved when friction between resin & barrel is max^m and friction between resin & screw is min^m. Helix angles ~~arg~~ of the screw are generally chosen to optimize the feeding characteristics & it may be varied between 12 & 20°.

Feed openings are usually centered over the barrel and are often round, with diameter equal to the inside diameter of the barrel. Alternatively, oval & rectangular openings with a length about 1.5 to 2 times the i.d. of barrel & a width of 1 dia.

Special batch or continuous metering assemblies may also be incorporated just before the feed hopper to permit feeding more than one material like when a colour masterbatch is mixed with some other resin. Sometimes preheating is done to remove moisture related problems & improving extruder output by providing part of the necessary heat to the resin which slightly reduces extruder power load.

~~Desi~~ SCREWS FOR SPECIFIC PLASTICS

1. Acetal copolymer – A metering type screw with at least a 4 or 5 flight metering section is recommended. In some applications 11 flights metering section screw is used. The compression ratio should be at least 3:1 with a preferred value of 4:1.

2. ABS – A single lead, full flighted, constant pitch screw with a progressively increasing root diameter and a compression ratio of 2:1 to 2.5:1 is recommended for most ABS grades. In addition, when extruding ABS/PVC alloys, ~~it is further~~ the screw should be chrome plated for corrosion resistance.

<u>Polycarbonate</u> – Screws having L/D ratios of 20:1 or greater are preferred. A full flighted, constant pitch screw with a progressively increasing root diameter and a compression ratio between 2:1 & 3:1 gives a smooth, homogeneous extrudate. This type of screw is also used to process rigid vinyl. The screw contains no sharp transitions from feed to compression to metering sections.

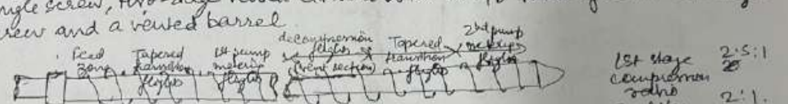
<u>Polyethylene</u> – ~~P~~ For PE, the screw & the barrel should be long, with an L/D ratio of at least 16:1 & ~~goes~~ can go upto 30:1 to provide a large area of heat transfer, compounding & homogenizing. The screw should be of constant pitch, decreasing channel depth with a compression ratio between 3:1 to 4:1.

<u>Nylon 6.6</u> – Nylon 6.6 melts at approx. 260°C. For this reason, an extruder with at least an L/D ratio of 16:1 is necessary & compression ratio of 4:1 is recommended. The screw geometry is similar to those used for PE.

<u>Dryblend extrusion of rigid PVC</u> – A large no. of rigid vinyl products are extruded directly from dry blended compounds, rather than the pelletized compounds. For these several extrusion systems are available.

a) Single screw, single stage non-vented extruder with an L/D ratio of 20:1 is used for dry blend extrusion. This type can be used provided some means of air removal, such as vacuum hopper, is available. Air pickup by the powder feed is a constant problem and limits extrusion rates. The powdered material ~~mo~~ should rotate at a slower rate than the screw so that it advances down the barrel easily. This can be done by increasing the frictional surface, which can be achieved by increasing the barrel length. In most cases a 24:1 L/D screw with a compression ratio of 3:1 has proven sufficient, provided means of removing air & volatiles is provided.

b) Single screw, two-stage vented extruder with a L/D ratio of 24:1 two stage screw and a vented barrel




This system provides a simple means of air & volatile removal, separately controlled ~~fetting~~ fluxing & metering functions. A two stage screw with a compression ratio of 3–3.5:1 & a pump ratio of 1.7–2.2:1 is regarded optimum for rigid PVC dry blend processing.

All screws ~~of~~ for single screw extrusion of PVC dry blends should be cored to accept oil cooling and the coring should extend to within 1/2 to 5/8 inch of the screw tip. Water or air have been proved inefficient of cooling.

c) <u>Twin screw & four screw extruders</u> – These types of extrusion systems are now gaining wide acceptance for rigid vinyl prodn. They offer advantages of lower formulation costs & higher output rates than single screw extruders. In a twin screw extruder with intermeshing screws, the relative motion of the flight of one screw inside the channel of the other acts as a wedge pushing the material from the back to the front of the channel. Since more physical mixing & shearing action takes place in the barrels, less heat is necessary for proper ~~fusion~~ fusion of the compound. Thereby reducing the level of necessity of heat stabilizers.

TYPICAL SCREW DESIGNS

| | Dimension | Rigid PVC | HIPS | LDPE | HDPE | Nylon | |
|---|---|---|---|---|---|---|---|
| D | Diameter | 4½" | 4½" | 4½" | 4½" | 4½" | [illegible] |
| L | Total length | 90 | 90 | 90 | 90 | 90 | 90 |
| F | Feed zone | 13½" | 27" | 22½" | 36 | 67½" | 0 |
| C | Compression zone | 76½" | 18 | 45 | 18 | 4½ | 90 |
| M | Metering zone | 0 | 45 | 22½ | 36 | 18 | 0 |
| P | Pitch | 4½" | 4½" | 4½" | 4½" | 4½" | 4½" |
| $H_1$ | Depth in M | 0.2" | 0.14" | 0.125" | 0.155" | 0.125" | 0.125" |
| $H_2$ | Depth in F | 0.60" | 0.60" | 0.60" | 0.65" | 0.65" | 0.60" |
| E | Thread width | ½" | ½" | ½" | ½" | ½" | ½" |

Total length starts at the forward end of the feed opening.

EXTRUDER BARRELS. — The function of the barrel is to house the screw & provide a transfer medium for heating & cooling. In earlier extruders, most barrels were nitrided to provide improved wear. In nitriding steels incorporating various amounts of alloying elements are heated in nitrogenous atmosphere. The nitrogen diffuses into the steel and reacts with the alloying elements to form a hard surface layer.

Lately, as pressures encountered in extrusion increased, the use of longer-wearing bimetallic barrels started. These barrels use linings based on a durable alloy about 1/16 inch thick. This is done by charging the alloy into a seamless metal tube, heated above its melting point, and centrifugally casted onto the tube.

More recently, newer techniques are being used to make the bimetallic barrels more stronger because of even higher pressures being encountered in extrusion. One technique is to cast the lining onto a thin walled steel tube and then shrink fit the tube into an outer casing with a thicker wall. Another technique is to machine the end of the barrel and shrink fit a reinforcing metal sleeve over it.

The need for heating & cooling the extruder barrels is important in most extrusion operations. This requires the installation of good heaters & controllers. Normally, the heat is applied by electrical heating which can either be conventional resistance heater type or by induction heaters type.

Sufficient heater capacity is required for the specific processing desired. Often, a watt density of 25–50 watts/sq. inch, based on the inside diameter, is desirable. The aluminium or alloy cast heater ~~represent are~~ tends to give good fit to the heated part & uniform element temp. as a result of the high thermal conductivity. An added advantage of these units is that water cooling tubes can also be embedded in them for cooling. It is desirable to have cooling capabilities in the barrels too. It can help accelerate cooling on shutdown or when a drastic drop in operating temp. is necessary. Cooling of at least some portions of the extruder is employed to remove the excess heat resulting from the screw working.

Cooling is commonly achieved by either water or forced air. Water
is more effective, but if not properly controlled, can cause severe
change in temp. which leads to upsetting in the uniformity of melt
temp., melt pressure and output. Typical water cooling systems
include tubes within the cast heater units or cooling coils embedded
in the barrel & jacket.

Air cooling is more gentle, but cannot remove large quantities of
heat of a liquid system. Typical air cooling is done with a series of
blowers corresponding to the heating zones.

DRIVES. – The power for extruder screw rotation is supplied by a
variable speed motor drive system. It is transmitted thru
a gear reduction unit, a coupling & the thrust bearing. Gear reducers
impart final speed and torque to the extruder screw. Most gear
reducers use double-reduction helical gears for ruggedness and to
hold ~~too~~ noise levels.

Thrust bearings absorb the thrust force exerted by the screw
as it turns against the material in the barrel. The operating pressure,
size of the extruder, & the operating speeds are important factors in
the thrust bearing specifications.

The motor size for the extruder must be sufficient to allow
for the energy required to work, melt & deliver the resin at the
desired output condition & rate. Higher outputs of resin at higher
screw speeds require more power than low outputs. The specific heat
of the resin is also a determining factor for power requirements.
As a thumb rule. many simple extrusions require 1 hp for every
10-15 lb/hr of product, but this value goes down to 3-5 lb/hr for
high temp, high screw speed.

Although DC drives are efficient over a wide range of speeds,
mechanical drives can also be used, however ~~the~~ a newer drive
system consists of a hydraulic unit powered by an electric motor.
The hydraulic units provide high available torque even at low speeds and
accurate speed control.

Screenpacks & Valves – Initially screenpacks were not only used to remove
contamination or coarse particles from melt
stream but also for developing pressure for better mixing.

In operation, the screen pack is backed up by a breaker plate
that has a many no. of round holes ranging from 1/8 to 3/16 inch in
dia. More recently, external screen changers have been developed
to frequently change the screenpacks. The packs are mounted outside
the extruder between head clamp & dies & are changed via mechanical
or hydraulic operation.

The use of valves in modern extrusion systems permits
control of pressure at higher levels so that breakage of screens is
avoided. Extruder valves vary in detail considerably, but usually
fall into two general types. The streamlined manually adjusted plug
which permits the melt to pass between it & a stationery seat is one
class of stationery valves, while the ~~valves with one portion~~ other
class is dynamic valve which usually have one portion of the valve
attached to the rotating screw & the other portion stationary so that there
is addnl. pressure generation at the end.

**Calculating Extruder Output** - Of the three sections of a well designed extruder screw, output is dependent on the metering section. If the geometry of this section is known, and if actual operating conditions can be assumed as known, it is possible to calculate the extruder output.

In the metering section of the screw, three kinds of melt flow may ex

1) **Drag flow** - This is the forward motion of the melt stemming from the conveying or pumping action of the screw with no flow restrictions.
2) **Pressure flow** - This means a theoretical back flow (or the loss of output) due to the restrictions in the system such as the die or any pressure control devices. It can be simply understood as that flow which one would obtain if screw rotation was stopped & the molten resin was forced under pressure from the die down the screw channel.
3) **Leakage flow** - This is defined as flow over the top of a screw flight into the preceding screw channel because of the presence of melt under pressure and clearance between the screw flight & the barrel wall.

The net output of the extruder screw can thus be known by this eqn

Output = Drag flow - Pressure flow - Leakage flow.

However since the leakage flow is dependent on the clearance between the top of the screw flight & the barrel wall. This dimension is of the order of 0.010 inch on most equipment, which lead to very small output losses. So commonly, leakage flow can be ignored without serious error.

The Output relationship can be presented as:

$$\text{Output } Q = \alpha N - \frac{\beta \Delta P}{\mu} \quad \text{lb/hr.}$$

where $\alpha$ and $\beta$ are functions of the metering section geometry, $\Delta P$ is the pressure drop in the metering section in psi & $\mu$ is the viscosity in the metering section.

N is screw speed in rpm,

$$\alpha = \frac{n \pi D b h \cos^2\phi \; F_d}{2} \quad \frac{\text{inch}^3}{\text{rev.}}$$

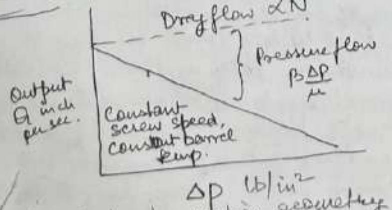
units.

- $n \rightarrow$ no. of parallel threads (1 for conventional screw)
- $D \rightarrow$ Nominal screw dia (inches)
- $b \rightarrow$ Length of one flight of the screw (inches)
- $h \rightarrow$ metering zone channel depth (inches)
- $\phi \rightarrow$ helix angle
- $F_d \rightarrow$ Drag flow shape factor (which is 1 if the ratio of channel depth to width is less than 0.1)

$$\beta = \frac{b h^3 \sin\phi \cos\phi}{12L} \cdot F_p \quad \text{inch}^3$$

- $L \rightarrow$ Axial length of metering zone.
- $F_p \rightarrow$ Pressure flow shape factor.

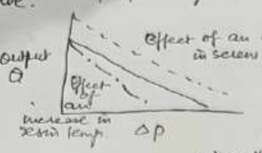
This can be described graphically with a "screw characteristic curve"




Output decreases as pressure drop increases.

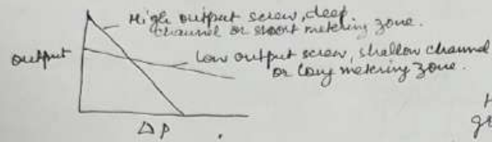
With a particular metering section geometry operating at constant speed & temp., drag flow is shown at zero pressure drop (or open discharge) & output decreases as pressure drop increases.

Effects of operating condition changes on the typical screw characteristic curve. ⑦




If screw speed is increased, the drag flow increases while the pressure flow remains fixed.
However, if barrel temp. is increased drag flow would remain unchanged, but pressure flow would increase because resin viscosity would decrease.

Effect of screw geometry on the S-C Curve




It has been found that a deep channelled metering section is unsuitable for high pressure extrusion, because the pressure flow losses have too great an effect on screw output.

$$Q = Q_D - Q_P - Q_L$$

Drag flow - $Q_D = \frac{\pi^2}{2} D^2 N h \sin\theta \cos\theta$

$Q_D \rightarrow$ Drag flow ($in^3/min$)
$D \rightarrow$ Barrel dia (inch)
$N \rightarrow$ Screw speed (rpm)
$h \rightarrow$ channel depth (inch)
$\theta \rightarrow$ Helix angle (17.8°)

Pressure flow - $Q_P = \frac{\pi D h^3 \Delta P \sin^2\theta}{12 \eta L}$

$Q_P \rightarrow$ Pressure flow ($in^3/sec$)
$\Delta P \rightarrow$ increase in pressure (psi)
$\eta \rightarrow$ viscosity ($lb\text{-}sec/inch^2$)
$L \rightarrow$ length of metering section (inch)

Leakage flow - $Q_L = \frac{\pi}{10} \times \frac{\pi D_1^2 \delta^3 \tan\theta \, \Delta P}{S L \eta}$

$Q_L \rightarrow$ Leakage flow ($in^3/sec$)
$D_1 \rightarrow$ Screw diameter (inch)
$\delta \rightarrow$ Flight clearance (inch)
$S \rightarrow$ flight width (inch)

Factors affecting extruder's Output.

| | Factor | Change | Output | |
|---|---|---|---|---|
| Material - | Shear viscosity | increases | Decreases | |
| | Elongation viscosity | " | " | |
| | Additives | " | + (lubricating oil) - (Filler) | |
| Feed - | Uniformity of Pellets | + | + | uninterrupted feeding is ensured |
| | Sphericity of pellets | + | + | Easier feeding. |
| Screw - | Diameter | + | + | |
| | Channel depth | + | + | |
| | Helix angle (up to 30°) | + | + | |
| Barrel | Grooved | + | + | Grooved barrel in the feed section ensures higher compression |
| Screenpack | No. & size | + | - | |
| | Back pressure | + | - | |
| Die | X-sectional area | + | + | |
| | Land length | + | - | |

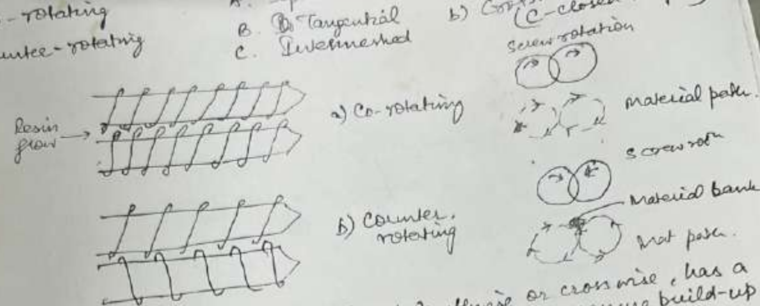
TWIN SCREW EXTRUDERS

→ TSE's are classified according to the following three categories.

Screw Rotation
1. Co-rotating
2. Counter-rotating

Intermeshing
A. Separated
B. Tangential
C. Intermeshed

Confinement
a) Lengthwise closed or open (L-closed or open)
b) Crosswise closed or open (C-closed or open)




Whether the screws are open or closed lengthwise or crosswise, has a direct effect on the conveying capability, mixing & the pressure build-up capacity of the system. e.g. the non-intermeshing systems are open lengthwise or crosswise & fully intermeshing. counter-rotating systems can be closed lengthwise & crosswise.

A screw system lengthwise open has a passage from the inlet to the outlet of the apparatus. This means that material exchange takes place lengthwise along the channel. In a closed arrangement the screw flights in the longitudinal direction are closed at intervals.

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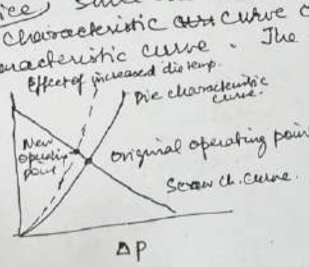
✓ Discussion so far ~~with~~ on extruder screw only. However the main source of pressure loss is due to the extruder die. The die is a restriction to flow & can be said as a pressure flow device. Since die & extruder always operate together, a die characteristic curve can be combined with the screw characteristic curve. The interaction of these two curves represents the operating point for the system under that particular combination of conditions.

Die output may be given as $Q_{die} = \frac{K\Delta P}{\mu_d}$

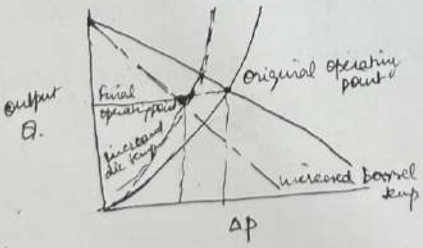
$K \rightarrow$ function of die geometry

$\Delta P \rightarrow$ pressure drop in die section

$\mu_d \rightarrow$ die section viscosity




If the die temp. is increased, the extruder operates at lower pressure with high output, because of decrease in melt viscosity in the die.




If operating temp. were changed by the same amount in both barrel & die, the net result would be no changed in output although the extruder will operate at lower pressure.

(2)

**Multiple screw extruders** – These have found use in processing specially to those materials which are heat sensitive like PVC, or in prodn of high quality rigid PVC pipe of large dia, extrusion of PS foam sheet & many other applns.

Mainly three types of arrangements are commercially important

2. ICRR – Intermeshing counter rotating
3. CRNI – Counter rotating Non-intermeshing
1. CORI – Co-rotating Intermeshing

~~1. ICRR was developed In this the extrusion speed depends on the intermeshing geometry & the screw speed.~~

1. **CORI** – For many years, CORI has been the universal compounder of choice. It operates at higher screw speeds with long barrels, advantageous especially for reactive processing. Their advantage arises from the movement of intermeshing surfaces in opposite directions, thus the melt free surface is continuously renewed & the screws clean each other. In addition, since at the intermeshing the material passes from one screw to the other (change of drag direction) there is low probability that the material would go through the gap. Thus there is no calendering pressure that may cause the screws to bend, which permits higher screw speeds & longer barrels.

2. **ICRR** – was developed as a (+)ve displacement screw pump for viscous, difficult fluids. The extrusion speed depends on the intermeshing geometry & the screw speed. The fully intermeshing ICRR has narrower distribution of residence times & better precision in controlling rapid rxns between liquid reagent & molten polymer than a CORI. The Low speed ICRR have been used for PVC compounding & foaming. At higher screw speeds, these can be used for incorporation of high viscosity toughening elastomer e.g. reactive extrusion of ABS. For some appln ICRR offers unique advantage of strong extensional flow field, able to disperse high viscosity ingredients in a low viscosity matrix.

3. **CRNI** – In CRNI the material flow is based on a drag, not on (+)ve pumping. There is a low shear stress field, responsible for the absence of dispersive mixing. However, the interchange of material between the screws provide good distributive mixing. The main advantage of CRNI is long enough residence time, sufficient to complete slow reactions. CRNI offers larger outputs & more interchange of material between the two screws than other type TSEs. These machines are frequently used for prepn of composites with fibrous fillers.

**Fundamental differences between SSE & TSE.**

| Function | SSE | TSE |
|---|---|---|
| Degree of channel fill | fully filled | Partially filled |
| Throughput Q is determined by | Screw speed N | Feed rate |
| Total strain | Independent on Q & N | Dependent on Q |
| Shear strain | Low | High, controllable |
| Material transport | By friction (drag flow) | Positive conveying |
| Material flow path | Smooth, regular helix | Tortuous, diverse |
| Heat transport | Ineffective | Effective |
| Liquid & powder additives | Pose problem | Do not pose problems |
| High viscosity additives | Impossible to disperse | Can be dispersed |
| Mixing capability | Poor | Good, adjustable |

| Function | SSE | TSE |
|---|---|---|
| Extruder length for melting | Long | very short |
| Extruder length for mixing | Long | short |
| Advantage | Easy to move, Inexpensive, theoretical description well developed | High flexibility, effective feeding, dev. mixing, reactive processing |
| Disadvantage | Lack of flexibility, poor feeding characteristic, ineffective devolatiser & mix, not good for reactive processing | Difficult fabrication, cost upto 10 times SSE. Theoretical analysis not developed well, Require accurate feeder |

## CO-EXTRUSION

A relatively new variation of extrusion involves the simultaneous,
or coextrusion, of multiple molten layers from a single extrusion system,
in some cases, involving as many as four different extruders. This technique
is mainly used for films, sheets, tubing & extrusion coating.

By using melt temperatures to bond the various p^ns together, coextrusion
becomes an economical competitor to conventional laminating techniques by
virtue of the reduced materials handling costs, raw materials costs & machine
time costs resulting from producing the structures in one pass. Pinholing
alongwith problems of delamination & entrapment of air between layers is
also reduced with co-extrusion.

Typical coextruded combinations include a variety of packaging films
that balance diff. plastics offering varying degrees of moisture resistance,
gas barrier properties, economies etc. e.g.

PE/Nylon/PE combo → used for medical & sterile packaged disposables
LDPE/HDPE → used for shrink film for wrapping & shopping bags (rigidity & low cost)
PS/PS foam → egg cartons & meat trays (PS - glossy attractive surface)
PP/Saran/PE/ coextrusions laminated to vinyl or styrene for food containers
PS/barrier plastics coextrusions for transparent cans.

In sheet area — ABS (for chem resistance)/PS (for economy). coex for refrigerator
door liners & margarine tubs.
Acrylic (for weather resistance)/PS (for economy) for outdoor building appl^ns
PS/Polysulfone co-ex for elec. & appliances where heat resistance
is necessary
ABS/rigid PVC coex. for shower stalls.

3 general concepts:

Laminar flow adaptor system

1) The various melts are combined just before the flow enters the die
via a special adapter. laminar flow keeps the layers from mixing
together so that the structure coming out of the die is as an
integral construction from the die. Mostly such systems are used with
flat coating or film dies.

Advantages of this system include - simplicity, lower cost, versatility
& the potential for better bonding since the layers are in contact for longer
periods within the die.

However the p^xs should reasonably match each other in viscosity.

2) Multiple manifold co extrusion — involves combination of the melts within
the die. Each inlet port leads to a separate manifold for the individual
layers involved. The layers are combined at or close to the final and
of the die & emerge as an integral construction through a single lip.
This technique can be used with flat or blown film dies.
Although MM coex can be costly it has the advantage of better
precise control of of individual layer thickness.

3) Multiple lip coextrusion — is designed to keep the individual layers
of plastic isolated from each other until they exit from the die.
The layers are subsequently combined after exiting while still molten
& just downstream of the die. Depending on the type of extrusion —
flat die, blown film, or coating - various techniques are used for ~~combining~~
combining the layers. For flat film dies - pressure rolls are used.
This technique is also costly but gauge control of individual layers is
more accurate, pinholes are eliminated & the system is easier to startup.

IMP: · melt temp. of each layer must be maintained above the freezing temp of
both layers, otherwise poor adhesion results because of a freeze line between
the two layers.