Endex International

Innovation for the Future

Endex Foam Extrusion General Information Guide

Section 01 – Foam Extrusion

Foam extrusion, in simple terms, consists of mixing a chemical foaming agent with a polymer, and extruding the mixture at a temperature high enough to melt the polymer. The chemical foaming agent reacts or decomposes, resulting in a gas being liberated which is dispersed in the polymer melt. Upon exiting the die the gas expands, and results in foam bubbles in the extruded material. Almost all typical extruders can be used for foaming if the following requirements are met:

a. The melt temperature profile of the extruder must be high enough to decompose the foaming agent and generate gas,
b. The pressure exerted on the molten polymer must be high enough to keep the gas dissolved in the polymer melt until it exits the extrusion die.

If the melt temperature profile is too low, it may cause only partial decomposition of the foaming agent which could make process more expensive. Undecomposed foaming agent particles may also result in agglomerates which can cause voids, irregular cell structures, poor surface appearance, or clog the melt filters or screen packs.

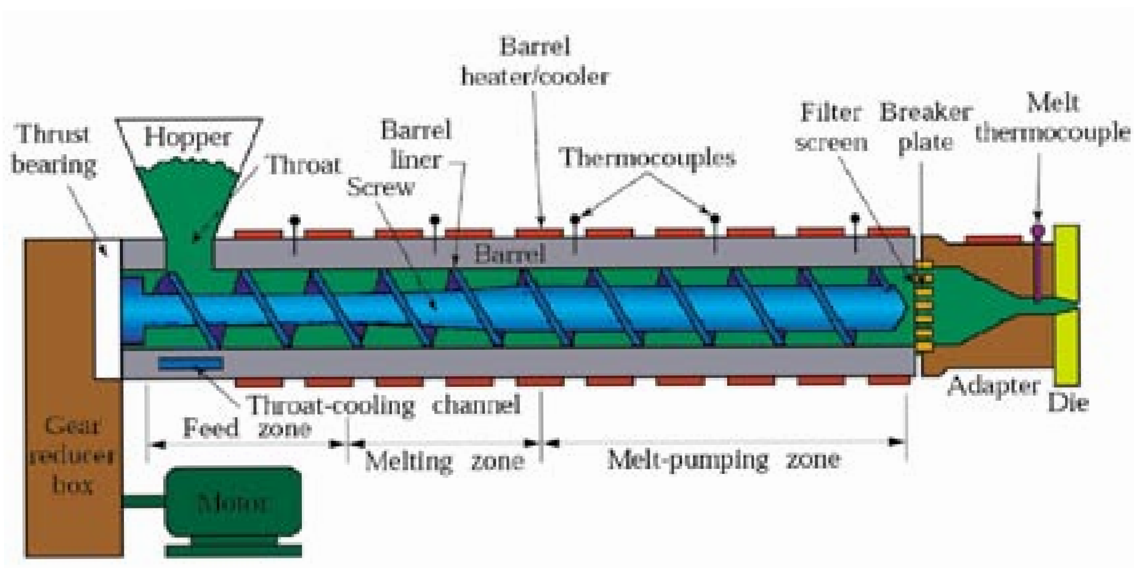
A pressure profile that is too low to keep the gas in the melt can cause foaming inside the extruder. Once this has occurred subsequent high pressure increases will not be sufficient to dissolve the gas back into the polymer, resulting in a coarse, irregular cell structures with broken and collapsed cells.

Coarse foams cause holes in flat films, rough surfaces (shark skin) in profiles, or collapse of blown film tubing.

Section 02 – Extrusion Line

The most often referenced number for an extruder specification is the L/D ratio (barrel length/barrel diameter) as this defines many of the operating characteristics for all types of extruders. The L/D ratio is a major factor in the effectiveness of the extruder and of the types of material that it can process.

The components of extrusion lines are similar whatever type of extruder is used and a typical layout is shown in schematic form below. The line consists of the basic extruder (drive, gearbox and screws), the extrusion die, the calibration units, the take-off, the saw (or other cutting device) and finally the treatment devices for final finishing and handling. The basic components of an extrusion line are shown below:



Basic functions of the extruder screw

The extruder screw has the following basic functions:

- To feed material along the screw, compressing it and removing volatiles.
- To soften the melt using externally applied heat and internally generated shear forces.
- To mix and produce a homogeneous melt without impurities.
- To apply a consistent, surge-free pressure to force the material through the die.

Section 03 - Foam Extruders

Most single screw extruders are suitable for chemical foam extrusion. The L/D ratio should be at least 24:1, and generally screws with an L/D ratio of 30:1 and higher are used. The temperature in the feeding zone should be lower than the initial decomposition temperature of the foaming agent used to prevent premature decomposition of the foaming agent.

Vented extruders like those used for PS and PMMA, can be used to produce foams but the vent should be plugged or sealed to prevent escape of the foaming agent gas. In the degassing zone a higher free volume can result in a slight pressure decrease, which could cause foaming in the extruder. It is possible to compensate for this pressure decrease by increasing screw speed thus increasing pressure on the melt prior to exit from the die.

The temperature of the feeding zone should be set to a temperature lower than the decomposition temperature of the chemical foaming agent, to prevent premature decomposition. As the polymer melts, the gas generated will dissolve in the melt due to the high pressures present, and can be very well distributed in a short period of time.

Section 04 - Extruder Screws

Screw configuration

Almost all common screws can be used for foam extrusion, provided there is no large pressure decrease in the melting and metering zones of the screw which can lead to unwanted premature foaming in the melt. Established screws for processing are three-zone screws (feeding-compression-metering/mixing).

Vented extruders

Good results can be achieved with degassing screws provided the conditions mentioned in paragraph 3 above are met.

Barrier Screws

Barrier screws have a tendency to premature foaming, caused by a decrease in the pressure between the barrier flight and the driving pitch. With short barrier segments, the pressure decrease can be compensated for by using higher screw speeds.

Section 05 - Screen-Filters and Melt Pumps

The use of fine mesh screen and screen changers are often not necessary in foam extrusion. Due to the presence of the foam structure, various impurities, gels, or additive agglomerates, are usually not visible and do not affect the foam product. If melt filters are used it is important to use screens that are rather coarse. This can help prevent a pressure drop after the screens which could result in premature foaming.

Melt pumps can improve the extrusion process by stabilizing the flow of material and increasing the pressure in the extruder barrel. In foam extrusion a pressure gauge should be placed where the melt enters the melt pump. The pressure reading on this gauge is used to control the screw speed, insuring a uniform melt output at the end of the extruder.

Section 06 - Dies

The proper design of an extrusion die is extremely important to achieve the desired shape and accurate dimensions of the extruded product. The function of an extrusion die is to shape the molten plastic exiting an extruder into the desired cross section depending on the product being made. The die provides a passage between the circular exit of the extrusion barrel and the more complex and often much thinner and wider die exit. Extrusion dies vary in shape and complexity according to the product being manufactured. It is best to design dies with short land lengths to maintain high melt pressure right up to the die lip. This is also valid for the production of foamed blown film. It should be noted, that the pressure characteristics of a given die can be affected by many factors, including the polymer, melt viscosity, temperature, targeted density reduction, output rate, and product dimensions.

There are five basic shapes of products made with extrusion dies, as illustrated in Table 1.

- **Film and sheet dies** are called slit dies as the basic shape of the die exit is a slit. Film is also made with annular dies as in the case of blown film.
- **Strand dies** make simple geometric shapes, such as circles, squares, or triangles.
- **Pipe and tubing dies** are called annular dies as the melt exits the die in the shape of an annulus. The inner wall of the annulus is supported with slight air pressure during extrusion.
- **Open profile dies** make irregular geometric shapes, such as "L" profiles or "U" profiles, and combinations of these.

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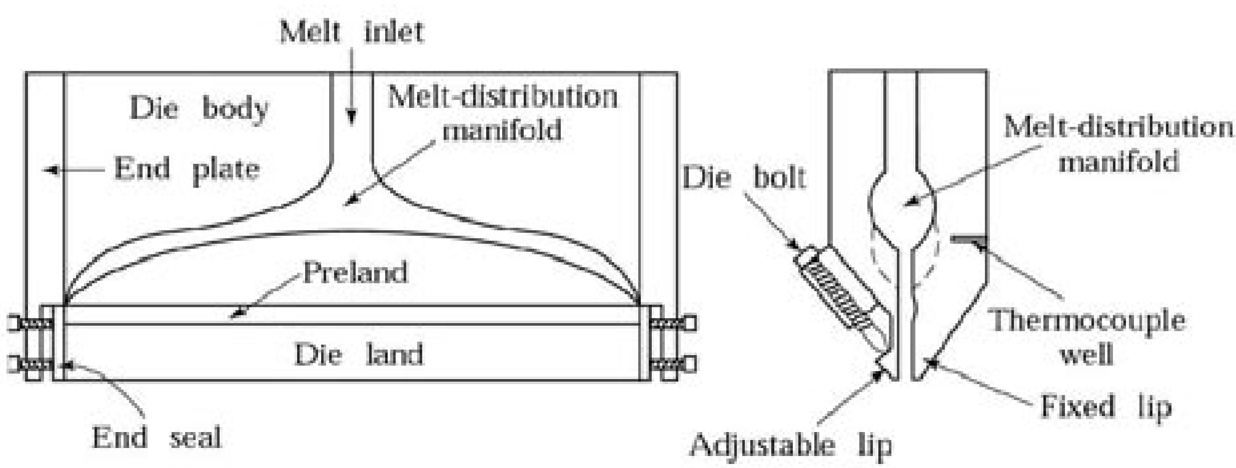
- **Hollow profile dies** make irregular profiles that have at least one area that is completely surrounded by material. Examples of hollow profiles can be simple, such as concentric squares to make a box beam, or a very complex window profile.
- **Co-extrusion dies** produce multilayered sheet and film material. They can make more economical products by sandwiching a low cost core material between more expensive materials, or create a composite material with improved properties by combining two or more materials.

Table 1 | Extrusion Shapes

Films	thickness	< 0.01 in. (2.54 mm)
Sheets	thickness	> 0.01 in. (2.54 mm)
Tubes	diameter	< 1.0 in. (25.4 mm)
Pipes	diameter	> 1.0 in. (25.4 mm)
Profiles	various	strand; open; hollow chamber

A schematic of a common sheet die, often referred to as a coat-hanger die, is shown in Fig. 1.

Fig. 1. Coat hanger-type sheet die concept



Note: LAND is the surface of an extrusion die parallel to the direction of melt flow.

When adjusting the distance of the opening in the die, the weight reduction target has to be considered. As a guide, for 30% weight reduction, the opening should be reduced by roughly 30% compared to a compact film of the same thickness, to compensate for the expansion of the foam.

When the melt is just exiting the die it is normally free of foam bubbles for a very short distance. Immediately after this 'clear area' the expansion of the gas bubbles can be seen. When a clear area can be seen it means there has been no premature foaming or expansion occurring in the extruder or die.

Co-extruded foam products are usually produced with a foamed inner layer, and solid outer layers. It is important to select the right materials since a foamed melt generally has better flow characteristics (lower apparent viscosity) than a solid melt of the same resin. If the layers differ too greatly in viscosity, it can result in poor or collapsed foam structure. Solid layers of resin with a melt flow value two to three times higher than the foam layer can be used to give good foam structure.

Section 07 – Extrudate Cooling and Sizing Hardware

With the exception of blown film and strand profiles, all extrudates require cooling and/or sizing. Table 2 summarizes the type of cooling and sizing hardware used for the various extrusion products.

Table 2 | Cooling and sizing devices for various extruded products

Product Type	Cooling and Sizing Device
Film and Sheet	Chill roll
Blown Film	External and internal bubble air
Profiles—strand	Water tank
Profiles—open and hollow chamber	Vacuum calibrators and water tank

Sheet and film

In the case of sheet extrusion, the cooling is achieved with a chill roll stack. The chill rolls are typically highly polished chrome-plated rollers that impart the surface gloss on sheet products and cool the extrudate while pulling the melt away from the die with a constant take-up speed. The average sheet thickness is achieved by the combination of extrusion screw rotational speeds and take-up speed adjustments. If the line speed taking the extrudate melt away from the die is greater than the average die exit speed, the thickness of the sheet decreases. This is called drawdown.

During the cooling process of foamed sheet, the following problems may be encountered:

- Insufficient foam formation – the time and distance between the die and the chill roll is not sufficient.
- The foam structure is flattened – the gap or nip of the chill-roll system may be too narrow.

When producing film, the foam bubbles may become highly stretched because the take-up speed is too high and as a result foam film density may increase. For some processes this stretch or orientation is deliberately used for special effects, as in decorative ribbons or packaging tapes.

Pipe and Tubing

In the case of pipe and tubing products, the nominal outer and inner diameters of the extrudate are set by selecting the appropriate size of the die pin and die land. The final outer dimension of tubing products is achieved with sizing rings that are typically placed in the vacuum water bath. The outer diameter of the tube is set with the sizing ring as the vacuum, which combined with a slight positive pressure inside the tube, forces the extrudate against the inner race of the ring. The inner diameter of the tube is set by adjusting the take-up speed of the extrudate relative to the average die exit speed. If the take-up speed is greater than the average die exit speed, the cross-sectional area decreases. Because the outer diameter of the tube is set with a sizing ring, the inner diameter will increase. Thus, the wall thickness of a tube is controlled this way.

Profiles

Profile extrusions are the most difficult to make because changes in take-up speed or screw rotational speed alone are not enough to compensate for deficient product dimensions. Profile extrudates are significantly affected by non-uniform die swell unlike sheet and tube products. Consequently, open profiles are more prone to cooling unevenly and thus may generate residual stresses in the solidified (frozen) extrudate that cause the product to bow.

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