Blown film extrusion

Blown film extrusion is a technology that is the most common method to make plastic films, especially for the packaging industry. The process involves extruding a tube of molten polymer through a die and inflating to several times its initial diameter to form a thin film bubble. This bubble is then collapsed and used as a lay-flat film or can be made into bags. Usually polyethylene is used with this process, and other materials can be used as blends with these polymers. A diagram of a polyethylene chain is shown in Figure 1 to the right.

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Background Theory on Polymers

In the cooling step of blown film extrusion, the amorphous, transparent melt crystallizes to form a translucent, hazy, or opaque film. The point where opacity begins in the bubble is known as the frost line.

The frost line height is controlled by several parameters: the air flow, film speed, and temperature difference between the film and the surroundings. Properties of the film, such as tensile strength, flexural strength, toughness, and optical properties, drastically change depending on the orientation of the molecules. As the transverse or hoop direction properties increase, the machine or longitudinal direction properties decrease. For instance, if all the molecules were aligned in the machine direction, it would be easy to tear the film in that direction, and very difficult in the transverse direction.
The Film Blowing Process

Typically, blown film extrusion is carried out vertically upwards, however horizontal and downward extrusion processes are now becoming more common \[3\], \[2\]. Figure 2 shows a schematic of the set-up for blown film extrusion. This procedure consists of four main steps:

1. The polymer material starts in a pellet form, which are successively compacted and melted to form a continuous, viscous liquid. This molten plastic is then forced, or extruded, through an annular die.
2. Air is injected through a hole in the center of the die, and the pressure causes the extruded melt to expand into a bubble. The air entering the bubble replaces air leaving it, so that even and constant pressure is maintained to ensure uniform thickness of the film \[3\].
3. The bubble is pulled continually upwards from the die and a cooling ring blows air onto the film. The film can also be cooled from the inside using internal bubble cooling. This reduces the temperature inside the bubble, while maintaining the bubble diameter \[2\].
4. After solidification at the frost line, the film moves into a set of nip rollers which collapse the bubble and flatten it into two flat film layers. The puller rolls pull the film onto windup rollers. The film passes through idler rolls during this process to ensure that there is uniform tension in the film. Between the nip rollers and the windup rollers, the film may pass through a treatment centre, depending on the application. During this stage, the film may be slit to form one or two films, or surface treated \[2\].

Advantages

Blown film generally has a better balance of mechanical properties than cast or extruded films because it is drawn in both the transverse and machine directions. Mechanical properties of the thin film include tensile and flexural strength, and toughness. The nearly uniform properties in both directions allow for maximum toughness in the film \[1\], \[2\].

Blown film extrusion can be used to make one large film, two smaller ones, or tubes that can be made into bags. Also, one die can make many different widths and sizes without significant trimming. This high level of flexibility in the process leads to less scrap material and higher productivity. Blown films also require lower melting temperatures than cast extrusion. Measured at the die opening, the temperature of cast film is about 220°C\[6\], whereas the temperature of blown film is about 135°C\[7\]. Furthermore, the cost of the equipment is approximately 50% of a cast line\[2\].

Disadvantages

Blown film has a less effective cooling process than flat film. Flat film cooling is done by means of chill rolls or water\[3\], which have significantly higher specific heat capacities than the air that is used in the blown film cooling process. The higher specific heat capacity allows the substance to absorb more heat with less change in the substance temperature. Compared to cast film,
blown film has a more complicated and less accurate method to control film thickness; cast film has a thickness variation of 1 to 2% versus the 3 to 4% for blown film; the resins used for casting typically have a lower melt flow index, which is the amount of polymer that can be forced through a standard die in 10 minutes according to a standard procedure. The melt flow index for cast film is about 5.0 g/10 min where as for blown film it is about 1.0 g/10 min. Consequently, the production rates for cast film are higher: cast film lines can reach production rates of up to 300m/min where as blown film lines are usually less than half this value. And finally, cast film has better optical properties, including transparency, haze, and gloss.

Common Problems

- Air entrapment between film layers and rollers – this may cause film scratching or wrinkling, or processing problems when winding up the film due to reduced friction. Possible solutions to this is using a vacuum to remove entrapped air or by using winding rolls with a diamond shaped groove in the rubber cover to increase surface area and decrease amount of entrapped air in the film.
- Large output fluctuations from the die – this causes thickness variations, and can be prevented by keeping the extruder clean and by using more consistently shaped pellets in the extruder.
- Melt fractures – these appear as roughness or wavy lines on the film surface, and can be eliminated by lowering the viscosity of the polymer melt. This can be done by increasing the melting temperature or by adding an internal lubricant to the material composition.
- Thickness variations in the film – this can be avoided by centering the die in the extrusion line before every run, adjusting the air speed of the cooling system, or by using heated die lips.
- Die lines on the surface of the film – this defect reduces the aesthetic appeal of the film, reduces optical properties, and weakens mechanical properties such as tear strength. This can usually be avoided by routinely cleaning the inner surfaces of the die and by refinishing scratched or roughened flow surfaces.
- Gels – these defects are small, hard globules encapsulated in the film or stuck on the film surface and reduce the aesthetic appeal of the film and cause stress concentration points which may result in premature failure. These are caused by overheating to the point of polymer degradation in the die, and can therefore be avoided by cleaning the inner surfaces of the die on a regular basis.

Optimization of the Process

Coextrusion

One way to improve the line efficiency of blown film extrusion is to implement coextrusion. This is the process of extruding two or more materials simultaneously through a single die. The orifices in the die are arranged such that the layers merge together before cooling. This process saves time because it extrudes two or more layers at the same time, and it provides a method with fewer steps to produce multilayer films. The production rate for a coextruded multilayer film of three layers is about 65m/min and the production rate for a single layer of blown film is about 130m/min. Thus, in order to produce 10,000m of a three layer multilayer film, it would take almost 4 hours using a single layer blown film process, and only 2 and a half hours using the coextrusion process. Furthermore, the film produced from the single layer process would require an extra step to glue the layers together using some sort of adhesive. Coextrusion is the least expensive means of producing layered films and the coextrusion system is capable of quick changeovers to minimize production line down time.
Minimizing the Melt Temperature

The efficiency of blown film extrusion can be improved by minimizing the temperature of the polymer melt. Reduction of the melt temperature causes the melt to require less heating in the extruder. Normal extrusion conditions have a melting temperature at about 190°C[15] despite the fact that the temperature of the melt only needs to be about 135°C[12]. However, it is not always practical to decrease the melting temperature by that much. By decreasing the melt temperature 2 to 20°C, the motor load can be decreased by about 1 to 10%.[16] Furthermore, reduction of the melt temperature causes less need for cooling, so there is a reduced use of the cooling system. Moreover, removing heat from the bubble is usually the rate-limiting factor in this extrusion process, so by having less heat in the polymer to remove, the rate of the process can be increased, thus yielding higher productivity. A way to maintain the melt temperature at a minimum is to choose an extruder that is matched to the specific processing conditions, such as the material of the melt, pressure, and throughput[12].

Heated Extrusion Die Lips

Typically, solutions to melt fractures involve decreasing the output or increasing the melt temperature to decrease the shear stress in the extruder. Both of these methods are not ideal because they both reduce the efficiency of the blown film line. Heated extrusion die lips can solve this problem. This targeted heating method allows for film extruders to be run at higher production rates with narrower die gaps while eliminating melt fractures.[17] Direct heat is applied to the surface of the polymer melt as it exits the die so that viscosity is reduced. Therefore, melt fractures, which are caused when trying to extrude too much of the polymer at one time, will no longer act as a limiting factor to increasing the production rate[17]. Furthermore, heated die lips use less energy than increasing the melting temperature because only the surface of the melt is heated and not the bulk of the liquid. Another benefit of using heated die lips is that thickness variations can be controlled by adding heat to certain areas along the die circumference to make the film at that position thinner. This would ensure that no excess material is used.[18]

Determine how much energy each of these processes can save per given volume of material. [expansion needed]

Applications

- Agricultural film
- Bags
- Industry packaging, shrink film, stretch film
- Consumer packaging, food wrap, transport packaging (shown in Figure 3)
- Laminating film
- Barrier film
- Multilayer film
- Research has been done to explore the incorporation of blown film extrusion into the large-scale manufacturing of carbon nanotube and nanowire films[19],[20]

Fig 3: Consumer food wrap from Plastic wrap Wikipedia article.

References