# A GUIDE TO POLYOLEFIN EXTRUSION COATING

lyondellbasell

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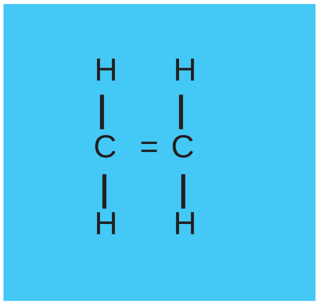

**Figure 1. Ethylene monomer molecular structure**

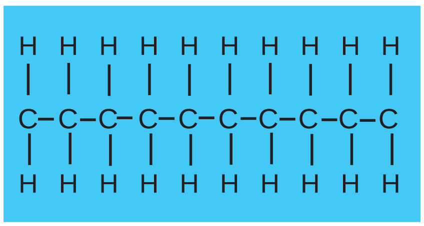

**Figure 2. Polyethylene molecular chain.**

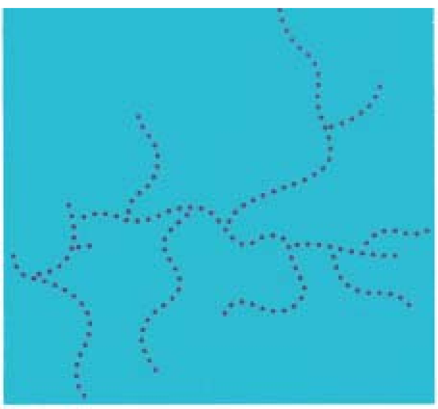

**Figure 3. Polyethylene chain with side branches.**


**Figure 5. Crystalline (A) and amorphous (B) regions in polyolefin.**

## What Are Polyolefins?

Polyolefins are thermoplastic resins polymerized from petroleum-based gases. The two principal gases are ethylene and propylene. Ethylene is the raw material for making polyethylene (PE) and ethylene copolymer resins and propylene is the main ingredient for making polypropylene (PP) and propylene copolymer resins. Polyolefin resins are classified as thermoplastics, which means that they can be melted, solidified and melted again. This contrasts with thermoset resins which, once molded, cannot be reprocessed. Most polyolefin resins for extrusion coating are sold in pellet form. The pellets are about 1/8 inch long and 1/8 inch in diameter, usually somewhat translucent and white in color. Polyolefin resins sometimes contain additives, such as thermal stabilizers, or are compounded with colorants, antistatic agents, UV stabilizers, etc.

## Effect of Molecular Structure and Composition on Properties and Processability

Three basic molecular properties affect most of the properties essential to high quality extrusion coatings. These molecular properties are:

- Average Molecular Weight
- Molecular weight Distribution
- Crystallinity or Density

These molecular properties are determined by the materials used to produce polyolefins and the conditions under which resins are manufactured. The basic elements from which polyolefins are derived are hydrogen and carbon atoms. For polyethylenes, these atoms are combined to form the ethylene monomer, $C_2H_4$, i.e., two carbon atoms and four hydrogen atoms **(Figure 1)**. In the polymerization process, the double bond connecting the carbon atoms is broken. Under the right conditions, these bonds combine with other ethylene molecules to form long molecular chains **(Figure 2)**. The resulting product is polyethylene resin.

Ethylene copolymers, such as ethylene vinyl acetate (EVA) and ethylene n-butyl acrylate (EnBA) are made by the polymerization of ethylene units with comonomers, such as vinyl acetate (VA) and normal butyl acrylate (nBA),

Polymerization of monomers creates a mixture of molecular chains of varying lengths. Some are short, others enormously long containing several hundred thousand monomer units. For polyethylene, the chains have numerous side branches. For every 100 ethylene units in the molecular chain, there are one to ten short or long branches, radiating three-dimensionally around the polymer chain **(Figure 3)**. Chain branching affects many polymer properties, including density, hardness, flexibility and transparency, to name a few. Chain branches also become points in the molecular network where oxidation may occur. In some processing techniques where high temperatures are reached, the resulting oxidation can adversely affect the polymer's properties.

### Density

Polyolefin resins are a mixture of crystalline and amorphous structures. Molecular chains in crystalline areas are arranged somewhat parallel to each other. In amorphous areas they are random. This mixture of crystalline and amorphous regions **(Figure 4)** is essential to the extrusion of good extrusion coatings. A totally amorphous polyolefin would be grease-like and have poor physical properties; a totally crystalline polymer would be very hard and brittle.

HDPE resins have molecular chains with comparatively few side chain branches. Therefore, the chains are packed closely together. The result is crystallinity up to 95%. LDPE resins have, generally, a crystallinity ranging from 60 to 75%, and LLDPE resins have crystallinity from 60 to 85%.

### Density Ranges for Polyolefin Extrusion Coating Resins

- LDPE resins range from 0.915 to 0.925 grams per cubic centimeter ($g/cm^3$).
- LLDPE resins have densities ranging from 0.910 to 0.940 $g/cm^3$.
- MDPE resins range from 0.926-0.940 g/cc.

- HDPE resins range from 0.941 to 0.955 g/cc.
- The density of PP resins range from 0.890 to 0.915 g/cc.

Higher density, in turn, influences numerous properties **(Table 1).** With increasing density some properties increase in value. However, increased density also results in a reduction of some properties, e.g., stress cracking resistance and low temperature toughness.

### Molecular Weight

Atoms of different elements, such as carbon, hydrogen, etc., have different atomic weights. The atomic weight of carbon is 12, and of hydrogen, 1. Thus, the molecular weight of the ethylene unit is the sum of its six atoms (2 carbon + 4 hydrogen) or 28. Every polyolefin resin consists of a mixture of large and small chains, i.e., chains of high and low molecular weights. The molecular weight of the polymer chain is generally in the thousands. The average of these is called, quite appropriately, the average molecular weight.

As average molecular weight increases, resin toughness increases. The same holds true for tensile strength and environmental stress cracking resistance (cracking brought on when a polyolefin object is subjected to stresses in the presence of liquids such as solvents, oils, detergents, etc.). However, because of increasing melt viscosity, drawdown becomes more difficult as average molecular weight increases.

**Table 1: General Guide to the Effects of Polyolefin Physical Properties on their Mechanical Properties and Processing.**

| Characteristic | As Melt Index Increases | As Density Increases |
|---|---|---|
| Chemical Resistance | Stays the Same | Increases |
| Clarity | Increases | Increases |
| Elongation at Rupture | Decreases | Decreases |
| Extrusion Speed | Increases | Increases |
| Drawdown | Increases | Increases |
| Flexibility | Stays the Same | Decreases |
| Gloss | Increases | Stays the Same |
| Heat Resistance (softening point) | Stays the Same | Increases |
| Impermeability to Gases/Liquids | Stays the Same | Increases |
| Low Temperature Flexibiity | Decreases | Decreases |
| Melt Viscosity | Decreases | Increases |
| Mechanical Flex Life | Decreases | Decreases |
| Stress Crack Resistance | Decreases | Decreases |
| Tensile Strength at Break | Decreases | Increases |
| Resistance to Blocking | Decreases | Increases |
| Stress Cracking Resistance | Decreases | Decreases |
| Tensile Strength at Rupture | Decreases | Increases |

### Melt Viscosity

Melt viscosity for polyethylene resins is expressed by melt index, a property tested under standard conditions of temperature and pressure. Melt index (MI) is inversely related to the resin's average molecular weight: as average molecular weight increases, MI decreases. Generally, a polyolefin resin with high molecular weight has a low MI, and vice versa.

Melt viscosity is an extremely important property since it reflects the flow of molten polymer. The resin's flow, when melted, increases with increasing MI. Therefore, polyolefins with a lower MI require higher extrusion temperatures. However, pressure can also influence flow properties. Two resins may have the same MI but different high-pressure flow properties. Therefore, MI **(Table 2)** must be used in conjunction with other yardsticks, such as molecular weight distribution, to measure the flow and other properties of resins. Generally, polyolefin extrusion coating resins are characterized as having medium, high and very high viscosity.

### Molecular Weight Distribution

The relative distribution of large, medium and small molecular chains in the polyolefin resin is important to its properties. When the resin is made up of chains close to the average length, the resin is said to have a "narrow molecular weight distribution" **(Figure 5**). "Broad molecular weight distribution" polyolefins have a wider variety of chain lengths. In general, resins with narrow molecular weight distributions have greater stress cracking resistance and better optical properties. Resins with broad molecular weight distributions generally have greater impact strength and better processability.

### Comonomers

Polyolefins made with one basic type of monomer are called homopolymers. However, many polyolefins, consisting of two or more

**Table 2: Polyolefin Extrusion Coating Resins**

| Resin | Melt Index Ranges* |
|---|---|
| LDPE | 3 to 15 |
| LLDPE | 3 to 15 |
| HDPE | 5 to 15 |
| EVA | 5 to 40 |

*** Melt Index describes the flow behavior of a resin at a specified test temperature (190°C, 374°F) and under a specified weight (2,160g). Resins with a higher melt index flow more easily in the hot, molten state than those with a lower melt index.**

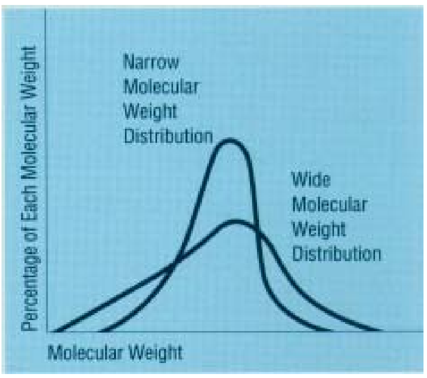


**Figure 5. Schematic representation of molecular weight distribution.**

**Table 3: Typical Additives Used with Polyolefin Extrusion Coating Resins.**

| Additive | Primary Benefit |
|---|---|
| Antistats | Static buildup resistance |
| Fragrances | Add attractive color, e.g. floral |
| Slip/Antiblock Agents | Improved coating-to-coating slip |

monomers, are called copolymers. Some extrusion coating grades of LLDPE, LDPE and HDPE are made with comonomers. These side chain groups provide specific additional properties to the resin. The common comonomers used with LLDPE and HDPE are butene and hexene. Vinyl Acetate (VA) is another comonomer used with ethylene to make extrusion coating grades, producing ethylene vinyl acetate (EVA).

Small amounts of VA are often added to polyethylene to produce a resin which extrudes much like polyethylene but yields tougher coatings of lower stiffness and potentially higher clarity. A wide range of properties are possible depending upon the proportion of VA incorporated in the resin and the synthesis conditions used to make the modified resins.

## Modifiers, Additives and Tie-Layers

Numerous chemical modifiers and additives can be compounded with polyolefin extrusion coating resins **(Table 3)** In some grades, chemical modifiers, such as thermal stabilizers and antistatic, antiblocking and slip agents, are added during resin manufacture. However, most extrusion coating converters prefer to let down additive concentrates into the polyolefins as part of the extrusion process. NOTE: the use of additives in extrusion coating may affect adhesion and heat seal properties in the final copolymer product. Contact the LyondellBasell technical service representative or your LyondellBasell sales representative for more information.

Tie-layers, such as LyondellBasell's PLEXAR® resins, are polyolefin-based resins which bond one type of polyolefin to a different material or to another polyolefin during coextrusion, coating or lamination. Tie-layers are specifically designed for use with barrier materials such as nylon (polyamide-PA), polyester (PET), polyvinylidene chloride (PVDC) and ethylene vinyl alcohol (EVOH).

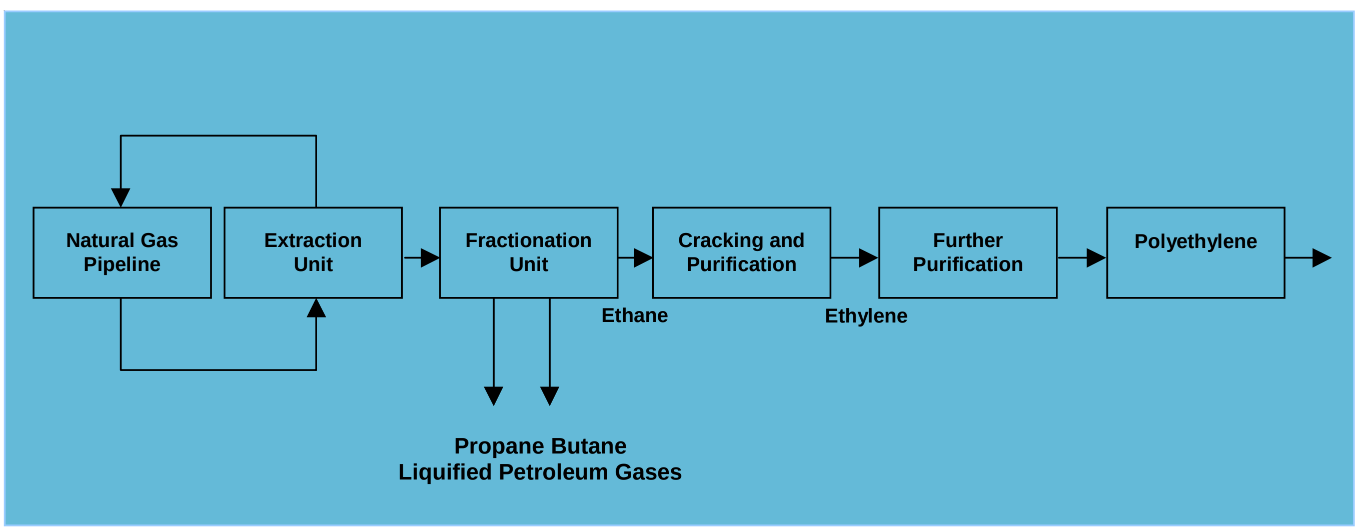


**Figure 6: Diagram of the polyethylene production process from liquified petroleum gas (LPG) to solid polyethylene pellets.**

Figure 7.  Linear Low Density Reactor at LyondellBasell's Morris, IL, plant

Figure 7a.  LyondellBasell's plant at Clinton, IA, where high and low density polyethylene and PLEXAR tie-layers are produced.

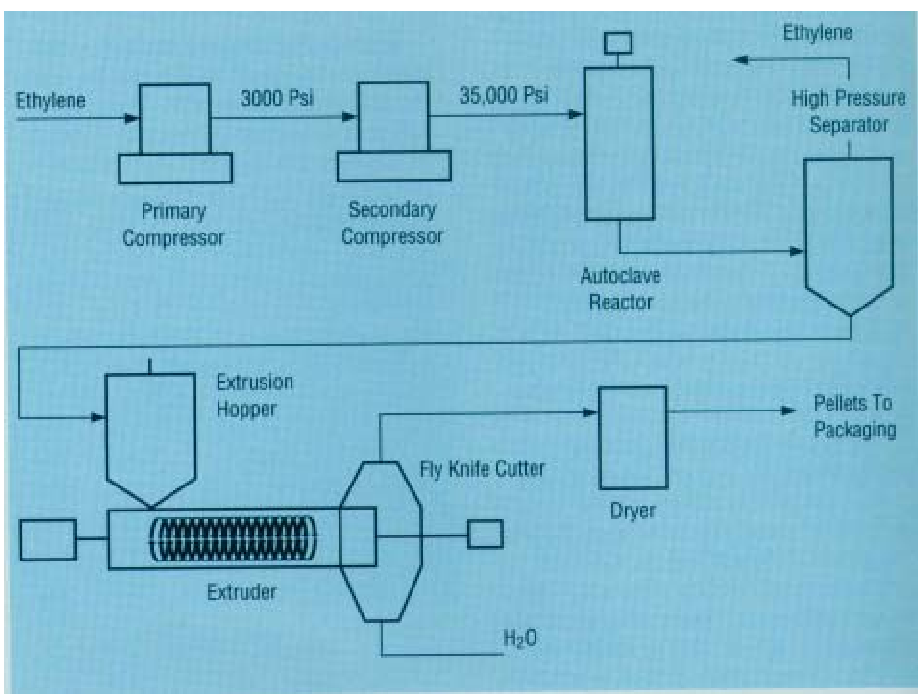


Figure 8.  Process diagaram for LDPE production in an autoclave reactor.

## How Polyolefins Are Made

High-purity ethylene and propylene gases are the basic feedstocks for making polyolefins **(Figure 6**). These gases can be a petroleum refinery by-product or they can be extracted from ethane-propane liquefied gas mixtures coming through pipelines from gas fields. High efficiency in the ethane/ propane cracking and purification results in very pure ethylene and propylene. This high purity is one of the key reasons LyondellBasell's polyolefin extrusion coating resins excel among commercially available LDPE, LLDPE, HDPE and ethylene copolymers. LyondellBasell Chemicals can produce polyolefins by more polymerization technologies and with a greater range of catalysts than any other supplier **(Figure 7 - 11)**.

### LDPE

To make LDPE resins **(Figure 8),** LyondellBasell uses high pressure, high temperature polymerization reactors. Ethylene gas, pumped into the reactors is combined with an initiator to synthesize LDPE. The LDPE formed flows to a separator where unused gas is removed. Next, the LDPE passes to a compounding extruder where additives can, if needed, be incorporated prior to pelletizing.

### HDPE

LyondellBasell produces HDPE for extrusion coating using a solution process in a three-stage reactor system. The multi-reactor technology provides precise control of molecular weight and molecular weight distribution, which impact processability and physical properties. With this technology the polymer is produced in solution at high temperatures. Downstream separation includes catalyst removal fromthe product that results in low catalyst residuals. The removal of catalyst residuals results in very low gel products. A schematic of the process is shown in **Figure 9**.

### LLDPE

LyondellBasell uses the gas-phase (GP) process to produce LLDPE **(Figure 10)**. The LLDPE processe is quite different from the LDPE process, but similar to the HDPE process. The major

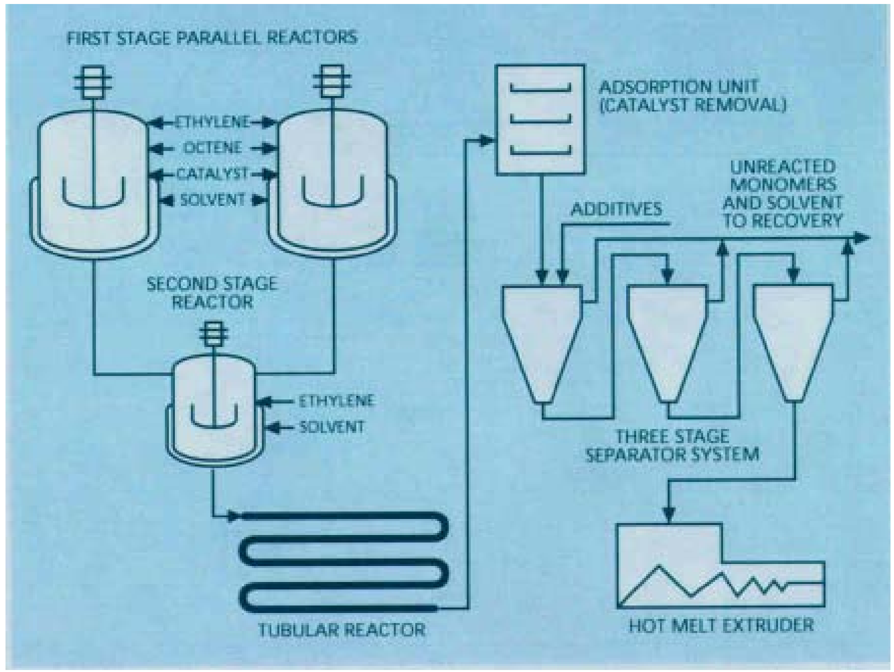


**Figure 9. HDPE solution process.**

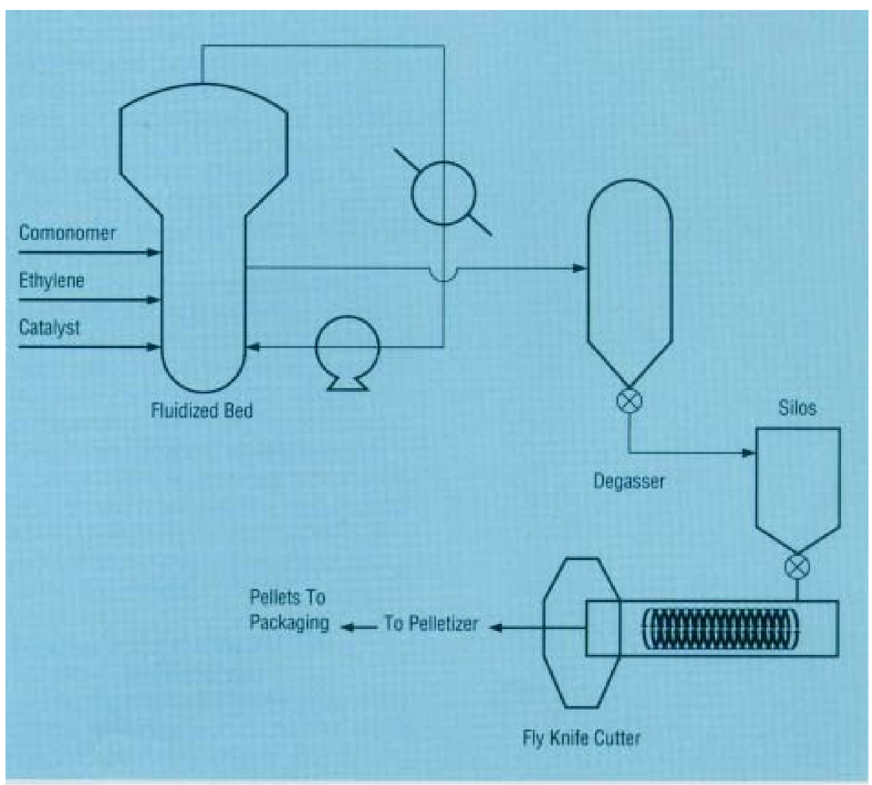


**Figure 10. Process diagram for LLDPE production in a gas-phase reactor.**

difference from the LDPE process is that low pressure, low temperature polymerization reactors are used. Another difference is that the ethylene is copolymerized with a butene or hexene comonomer in the reactor. A final distinction is that the polymer exits the reactor in granular form and the granules are compounded with additives in a finishing extruder and pelletized. HDPE resins also can be made in these reactors.

### Polypropylene

For making polypropylene (PP), LyondellBasell uses a vertical, stirred fluidized-bed, gas-phase reactor **(Figure 11)**. LyondellBasell was the first PP supplier in the United States to use gas-phase PP technology. This process is more energy efficient and produces a more uniform product than other PP manufacturing processes.

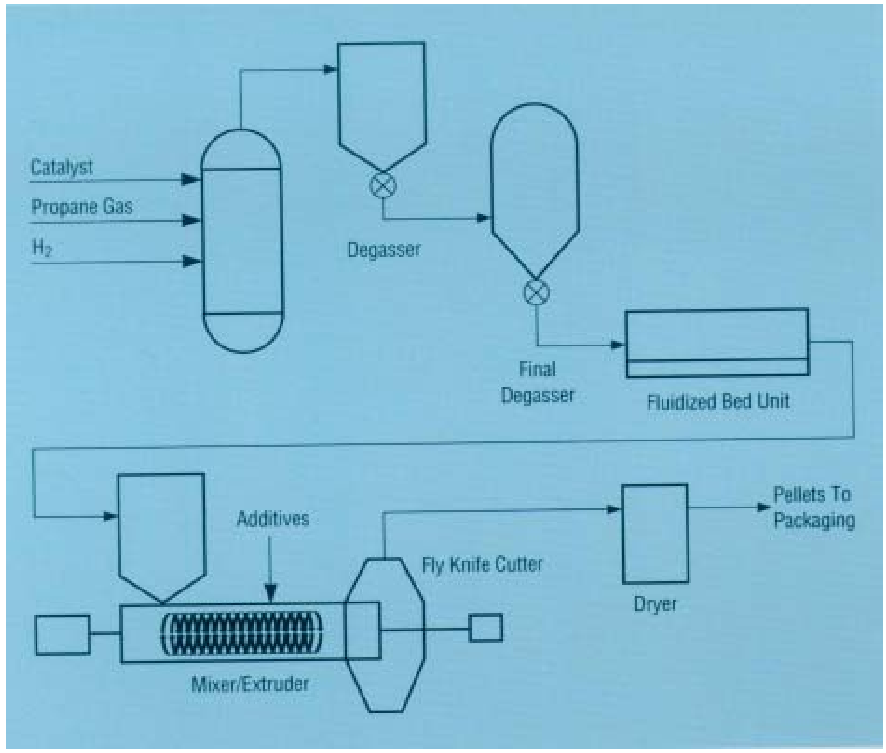


**Figure 11. Process diagram for polypropylene production.**

## Polyolefins for Extrusion Coating

In extrusion coating, resin is melted and formed into thin hot film, which is coated onto a moving, flat substrate such as paper, paperboard, metal toil or plastic film. The coated substrate then passes between a set of counter rotating rolls that press the coating onto the substrate to ensure complete contact and adhesion.

Extrusion laminating, also called sandwich laminating, is a process related to extrusion coating. However, in extrusion laminating, the extrusion coated layer is used as an adhesive layer between two or more substrates. A second layer is applied to the extrusion coating while it is still hot and then the sandwich is pressed together by pressure rolls. The extrusion coated layer may also serve as a moisture barrier.

Substrates that can be coated with polyolefins include paper, paperboard biaxially-oriented polypropylene (BOPP), biaxially-oriented nylon (BON), polyester and other plastic films, metal foil, fabrics and glass fiber mat.

### Resins for Extrusion Coating

LyondellBasell offers a wide range of resins for extrusion coating, including PETROTHENE® low density polyethylene (LDPE), linear low density polyethylene (LLDPE), and ALATHON® high density polyethylene (HDPE) and ULTRATHENE® ethylene vinyl acetate (EVA) copolymer.

### Properties of Substrates Coated with Polyolefins

The basic reasons for applying a polyolefin extrusion coating to a flexible substrate are to:

- Provide moisture barrier to either keep moisture out of packaged goods or to keep moisture in
- Increase tear, scuff and puncture resistance
- Gain a heat sealable surface
- Provide grease, oil and chemical resistance
- Provide adhesion between multiple substrates
- Improve package appearance

### Applications for Polyolefin Extrusion Coated Products

Some important applications for polyethylene-coated substrates are:

- Food board used to make cartons for packaging milk, liquid, powdered and solid foods, chemicals, fertilizers and resins
- Food pouches, such as those used for sugar and powdered food
- Multiwall bags, such as are used for shipping foodstuffs, chemicals, fertilizers, and plastic resins
- Lumber and steel overwrap
- Moisture barriers
- Cheese wrap
- Document sealing
- Medical packaging
- Liners for cartons, corrugated shipping containers, fiber drums, etc.
- Vacuum-forming materials for blister packaging and other special types of packaging
- Book or booklet covers
- Military packaging

**Other Products from LyondellBasell** offers an extensive range of polyolefin resins, engineering resins and polyolefin-based tie-layer resins not only for extrusion coating, but also for film extrusion, injection molding, blow molding, sheet and profile extrusion, wire and cable coating, hot melt coatings and adhesives, powder coating, blending and compounding and flame retardant applications. LyondellBasell also produces several chemicals, including vinyl acetate monomer, ethyl alcohol, ethyl ether and methanol, Information on all these products also can be obtained from your LyondellBasell sales representative.

## LyondellBasell Works Closely with Processors

As mentioned previously, LyondellBasell offers a wide range of polyolefin resins for extrusion coating. Working on new developments in extrusion coating as well as assisting customers with current problems and application projects is a section of our Technical Service and Development Department, part of LyondellBasell's Cincinnati Technology Center. The Cincinnati Technology Center is a state-of-the-art facility that brings together all of LyondellBasell's basic and applied research efforts under one roof. Production level plastics processing machinery is also located there, including a full-scale extrusion coater with three extruders capable of five-layer coextrusion coatings for use in product evaluation, product development and polymer and product testing.

LyondellBasell can also produce polyolefin resins with different performance capabilities by modifying the resins' three basic molecular properties via changes in reactor conditions and by adding comonomers, modifiers and additives. Processors can work closely with their LyondellBasell sales representative and technical service representative to determine which PETROTHENE, ALATHON or ULTRATHENE resin best meets their extrusion coating needs.

### Shipping and Handling Polyolefin Extrusion Coating Resins

Keeping polyolefin resins clean is of utmost importance. Contaminated resins can produce poor products. Polyolefin resins are shipped to processors in rail cars, hopper trucks, 1,000-and 1,500 pound polyethylene lined corrugated boxes and 50-pound bags. Strict quality control throughout resin manufacture and subsequent handling, through delivery to the processor, ensure the cleanliness of the product. When bulk containers are delivered, the processor must use clean, efficient procedures for unloading the resin. Maintenance of the in-plant material handling system also is essential. When bags and boxes are used, care must also be taken when opening the containers, as well as covering them as they are unloaded and used.

CAUTION: It is not recommended that reground resin or trim be used for extrusion coating. Gels, adhesion problems and taste and odor concerns can result from the use of regrind material

## The Extrusion Coating Process

There are four basic stages in the extrusion coating process:

1. Resin handling/conditioning
2. Substrate handling and surface preparation
3. Extrusion coating
4. Coated substrate takeoff

### Resin Handling/Conditioning

The production of high quality extrusion coated substrates requires particularly close attention to preventing resin contamination during production, storage, loading and shipment. Since polyolefin resins are non-hygroscopic (they absorb virtually no water), they do not require drying prior to being melted in the extruder.

### Resin Transfer System

One of the best ways to improve polyolefin resin utilization is to eliminate contaminants from transfer systems. Whenever a polyolefin resin is transferred by a current of air, the possibility of contamination exists. Dust, fines and other polyolefin detritus left behind in the transfer system can plug filters or other components, resulting in the starvation of the extruder. Occasionally, large clumps of polyolefins from previous transfers, sometimes called “angel hair” and “streamers,” may accumulate in a silo and plug the exit port. All of these problems can result in extruder down-time, excessive scrap and the need to spend time and money to clean silos, transfer lines and filters.

Many transfer systems consist of smooth bore piping that conveys the resin from hopper cars to storage silos or holding bins. Some systems also may be designed with long radius bends. A polyolefin pellet conveyed through a transfer line travels at a very high velocity. As the pellet comes in contact with the smooth pipe wall, it slides and slows down due to friction. The friction, in turn, creates sufficient heat to raise the pellet's surface to the resin's melting point. As this happens, a small deposit of molten polyolefin is left on the pipe wall. This deposit solidifies almost instantly. Over time, these deposits lead to a build-up called “angel hair.”

As the pellets continuously come in contact with the pipe wall, such as along the curved outside surface of a long radius bend, the deposits of polyolefin become almost continuous and streamers are formed. Eventually, the angel hair and streamers are dislodged from the pipe wall and find their way into the extrusion process, the storage silo or the transfer filters. The size and number of streamers formed increase with increased conveying air temperature and velocity and are also greater with smooth bore piping than with other kinds of handling systems.

Since smooth piping is a leading contributor to angel hair and streamers, the logical solution is to roughen the interior wall of the piping. This roughness will cause the pellets to tumble instead of slide along the pipe, thus decreasing the formation of streamers. However, as the rapidly moving polyolefin pellets come in contact with an extremely rough surface, small particles break off, and fines or dust are created. Two specific finishes for materials handling systems have proven to be the best performers and give the longest life:

- A sand blasted finish of 600 to 700 RMS roughness. This finish is the easiest to obtain; however, due to its sharp edges, it initially creates dust and fines until the edges become rounded with use.

- a finish achieved by shot blasting the piping with a #55 shot of 55-60 Rockwell Hardness to produce a 900 RMS roughness. Variations of this surface finish are commonly known as “hammer finished” surfaces. The shot blasting allows deeper penetration and increases hardness, which in turn leads to longer surface life. The rounded edges obtained minimize the initial problems encountered with dust and fines. They also reduce metal contamination concerns associated with the sandblasted finish.

Whenever a new transfer system is installed or when a portion of an existing system is replaced, the interior surfaces should be treated either by sand or shot blasting. The initial cost of having this done is far outweighed by the prevention of future problems.

Eliminating long radius bends where possible also is important **(Figure 12).** Long radius bends are probably the leading contributor to streamer formation. When pipe with long bends is used interior walls should be sand or shot blasted as described above. The use of self-cleaning stainless steel “tees” in place of long bends prevents the formation of streamers along the curvature of the bend **(Figure 13)** by causing the pellets to tumble instead of slide. Some loss of efficiency within the transfer system occurs when this method is used, however. By making sure that sufficient blower capacity is available, the required transfer rate can be maintained and clogging of the transfer lines prevented.

The transfer piping should be rotated 90° periodically. Resin pellets tend to wear grooves in the bottom of the piping as they are transferred. The grooves contribute to the formation of tines and streamers. Regardless of the type of equipment used or the materials transferred, the transfer system should be maintained and kept clean, Periodic washing of silos and holding bins reduces the problem of fines and dust buildup. Other steps used to eliminate contamination include:

- Cleaning all filters in the transfer system periodically.
- Ensuring that the suction line is not lying on the ground when the system is started. This prevents debris or gravel from entering the system.
- Placing air filters over hopper car hatches and bottom valves during unloading to prevent debris or moisture from contaminating the resin.

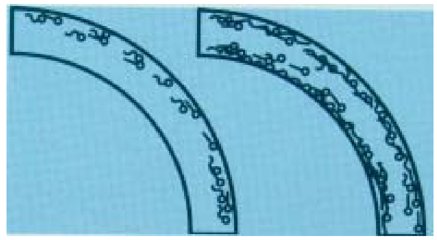

**Figure 12. Interior surfaces of long radius blends should be roughened to minimize “angel hair” and streamer formation in transfer systems.**

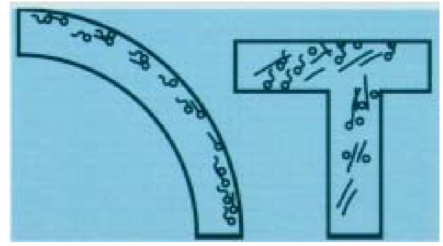

**Figure 13. Eliminate long radius blends where possible by using self-cleaning stainless steel “tees” instead. These “tees” prevent the formation of streamers along the curvature of the bend.**

Courtesy of HydReclaim Corp.

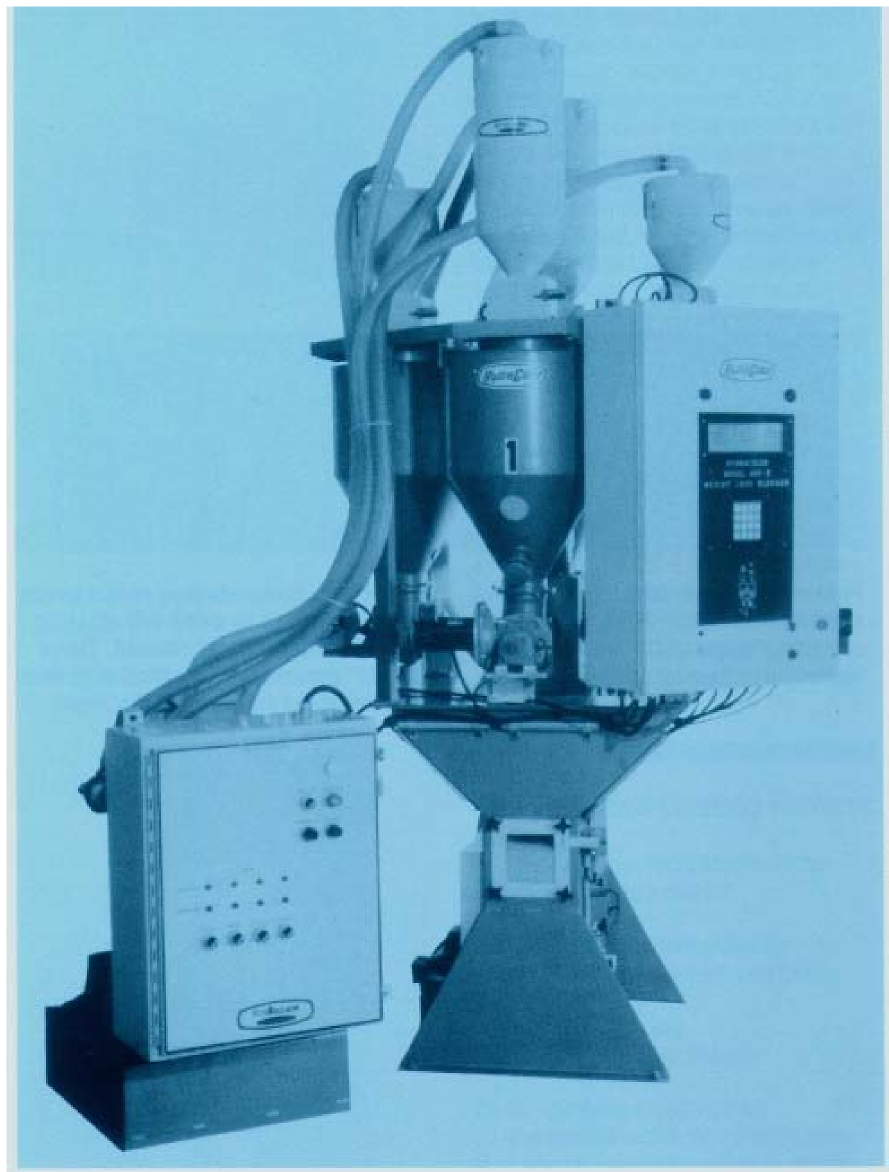

**Figure 14. Gravimetric blending units accurately measure components in polyolefin extrusion.**

Courtesy of Black Clawson

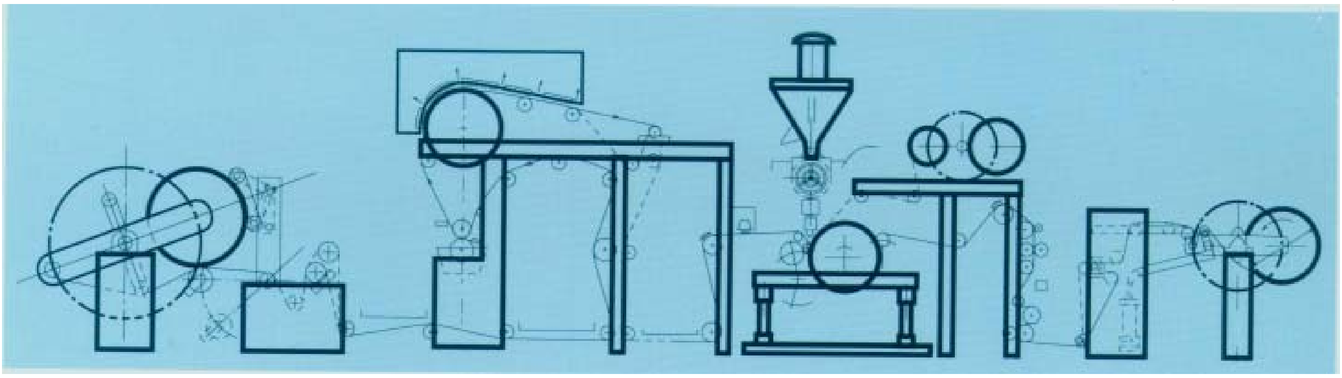

**Figure 15. Schematic diagram of an extrusion coating line.**

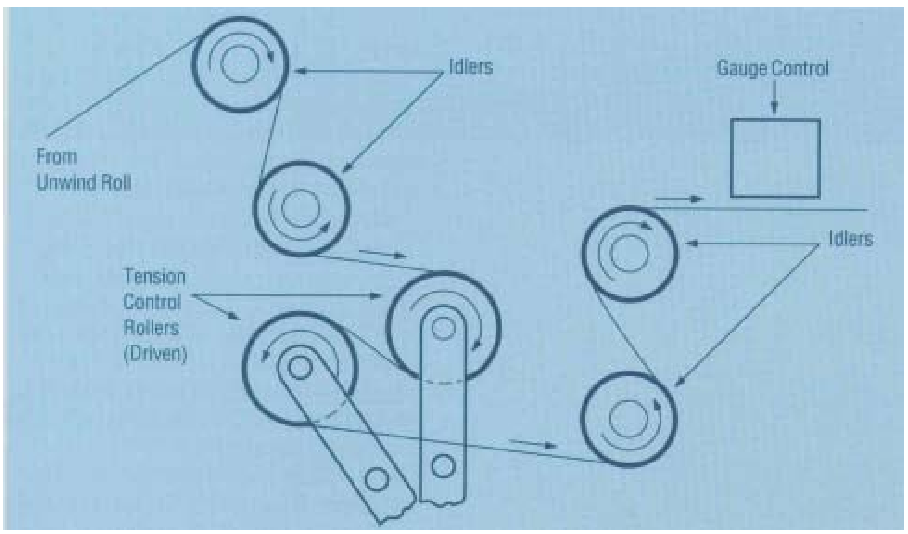


**Figure 16. Schematic drawing of tension control equipment for the unwinding substrate. The arrows indicate the motions of the driven tension rolls, idlers, substrate and the direction of the outward pressure on the rolls.**

- Initially purging the lines with air and then with a small amount of product prior to filling storage silos or bins. Let blowers run several minutes after unloading to clean the lines. This reduces the chance of cross-contamination of product.

Information regarding transfer systems and types of interior finishes available can be obtained from most suppliers of material handling equipment. Complete systems can be supplied which, when properly maintained, will efficiently convey contamination-free product.

## Blending With Colorants and Additives

On-the-machine blending units consist of multiple hoppers which feed different resin compound ingredients **(Figure 14).** Colorant or additive concentrates and base resin are combined using either volumetric or weight-loss feeding (gravimetric) techniques, the latter usually more accurate. Microprocessor controls monitor the amount of materials fed into a mixing chamber. Recipes can be stored in the control unit for instant recall.

Central blending units also can be used when much higher throughput is needed than possible with on-the machine blenders. Transfer to the extruder is by a central vacuum loading system.

## Substrate Handling and Surface Preparation

The extrusion coating process starts with feeding the substrate to the coating rolls from a “pay-off” roll (unwind) or reel **(Figure 15).** As the substrate comes off the pay-off roll, the diameter of this roll decreases. Without some compensating force, usually web tension, the decreasing diameter of the pull-off roll would manifest itself in non-uniform tension in the unrolling substrate. Without uniform tension, the coating is inconsistent.

Web tension is the amount of pull on the moving substrate per unit of its width. Web tension, measured in pounds per inch of width per mil thickness (lbs/in. width/mil), varies with the type of substrate used **(see Table 4, Figure 16).**

**Table 4: Typical Web Tensions for Extrusion Coating**

| Substrate | Tension lbs/in (mil) |
|---|---|
| Aluminum Foils | 0.5 - 1.5 |
| Cellophane | 0.5 - 1.0 |
| Acetate Film | 0.5 |
| Nylon Film | 0.15 - 0.5 |
| Paper (15-80 lb/ream) | 0.5 - 2.5 |
| Paperboard (8-30 pt.) | 3.0 - 11.0 |
| Polyester Film | 0.5 - 1.0 |
| Polyethylene Film | 0.25 - 0.3 |
| Polypropylene Film | 0.25 - 0.3 |
| Polystyrene Film | 1.0 |
| Polyvinylidene Film | 0.05 - 0.2 |
| Vinyl | 0.05 - 0.2 |

Source: TAPPI

To compensate for slack, automatic web tension control must be provided for the unrolling substrate. Unwinder roll designs include the following types **(Figure 16):** single roll, non-indexing dual roll, roll frame, dual width turret rollstand, phantom shaft and cantilevered rollstand.

Two types of roll braking are used with unwinders: surface braking and center braking. In surface braking, a roll is forced against the substrate roll as it unwinds. The two rolls thus turn in opposite directions. In center braking, a friction brake on the unwind spindle acts as a tension control.

To change from a nearly empty substrate roll to a new, full roll without interruption (or with only a slight slow-down) "flying-splice" equipment is required **(Figure 17).** The flying-splice set-up can be fully automatic. In some types of flying-splice unwind equipment, the ball bearings for the core shafts for both substrate rolls (the running one and the new one) are mounted on two tracks on top of the side frames of the unroll stand. When most of the substrate on the running roll has come off, this roll moves forward by a handwheel. Then the new, full roll is lowered into its bearings on the stand. Heavy lifting equipment is needed for this operation. The old roll, its diameter decreasing as it runs out, is still unreeling during this process.

Glue is applied along the leading edge of the substrate on the new roll. The driving rings are moved against the bottom of the new roll as it is brought up to the required rotating speed. Now, the new roll of substrate is moved against a bumper roll over which the substrate from the old roll is traveling. The glue connects the new roll's beginning edge with the tail of the expiring old roll. Concurrently, a cut-off knife cuts the expiring web from the old roll. The extrusion coater now is fed from the new roll and the almost empty core of the old roll is lifted off the stand.

Flying-splice equipment permits long, continuous runs at high speeds. On smaller equipment, connecting the webs of the new and the expiring rolls can be done by attaching a separate strip of substrate with adhesive on one side onto the beginning of the new roll. The rolls are then moved together. When the adhesive adheres to the tail of the expiring roll, this roll of substrate is cut. In extrusion laminating, the second substrate feeds into the nip over the chill roll from a second unwind roll.

## Precoaters

Prior to extrusion coating, substrates often pass through a preconditioning and/or pretreater station(s) to enhance adhesion. Generally, the priming/surface treatment unit is located in-line, just after the substrate unwinding unit and close to the extrusion coating station. Occasionally substrate preconditioning occurs off-line.

The three methods generally used to precondition substrates are chemical priming, flame treatment and corona discharge treatment. The choice of preconditioning method depends largely on the type of substrate to be extrusion coated. Metal foils almost always require pretreatment, mainly to ensure a clean surface. Some plastic films

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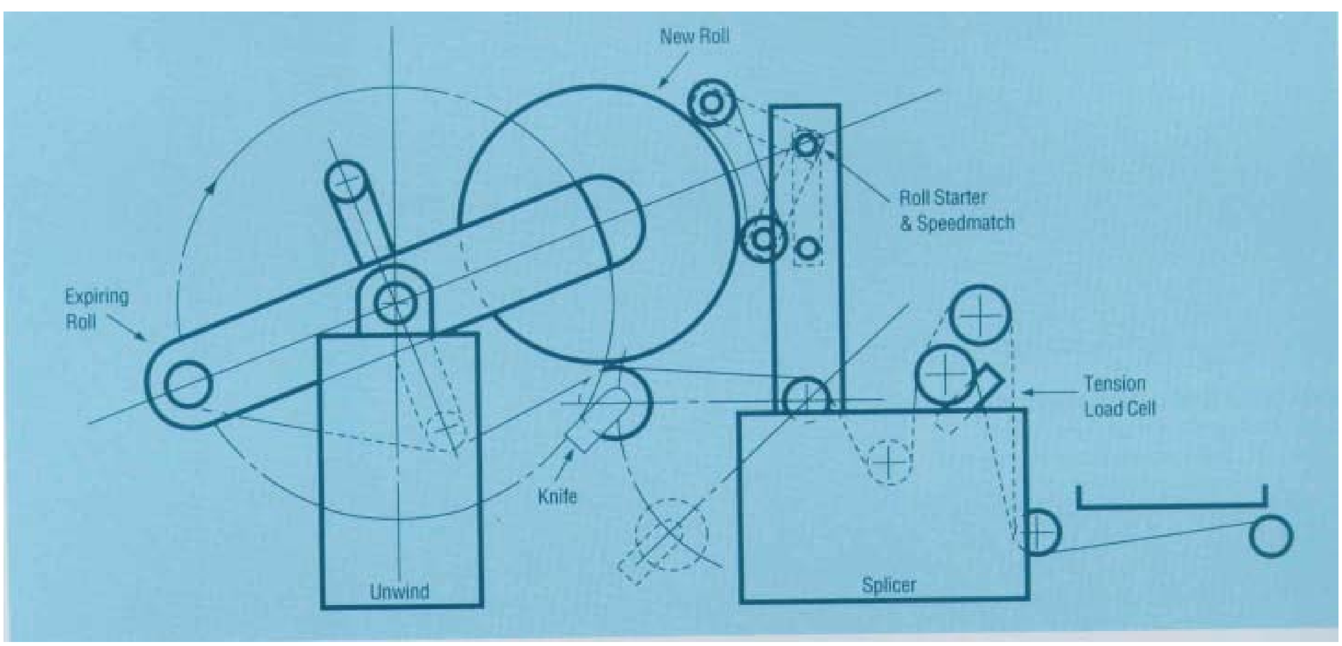


**Figure 17. Flying Splice Unwind System**

need pretreatment, often a combination of both corona discharge and chemical primer. Corona treatment of the film surface is used to improve the adhesion of the chemical primer to the film.

The extruded polymer web can also be treated via an in-line ozonator to enhance adhesion to a pretreated substrate **(Figure 18).**

## Primers

Primers serve two main purposes: to clean and decontaminate the substrate surface and to enable two different surfaces to adhere to each other through dipole interaction, hydrogen bonding, covalent bonding, van der Waals forces or a combination of these effects.

Primers should not be confused with tie-layers, which are extruded adhesives. Tie-layers are applied at the extrusion coating stage of the process and not as a preconditioning treatment.

Primers commonly used in extrusion coating are listed in **Table 5**.

Priming equipment comes in many designs and sizes **(Figure 19)**, including reverse roll coaters, offset gravure coaters, smooth roll coaters, kiss coaters, knife coaters, air-blade coaters wire-wound rods and metering rollers. The choice of type and size usually depends on the substrates to be coated, the viscosity of the primer

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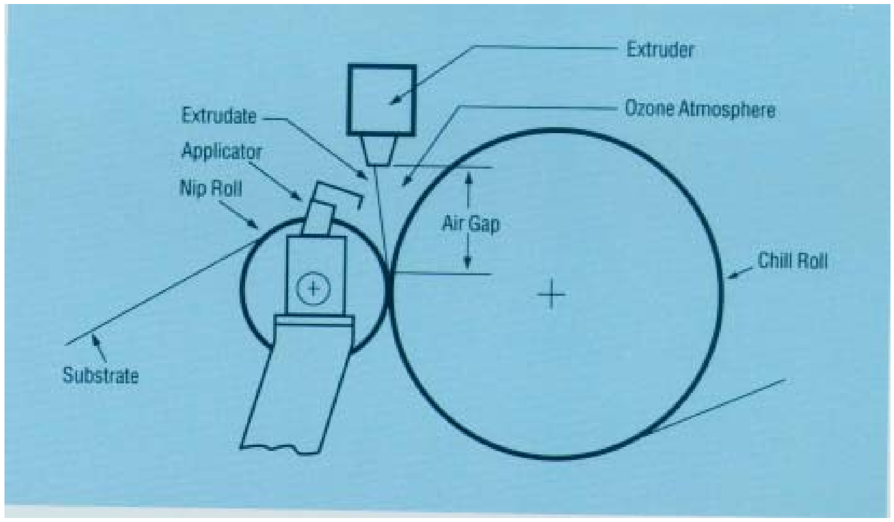


**Figure 18. Ozone air is generated in a remotely located ozone chamber and carried through flexible hose to the appicator which distributes the ozone air evenly over the entire width of the extrudate.**

**Table 5: Primers Used in Extrusion Coating**

| Primer | Adhesion Performance | | | Chemical Performance | | |
|---|---|---|---|---|---|---|
| | To Paper | To Foil | To Film | Heat Resistance | Moisture Resistance | Chemmical Resistance |
| Shellac | P | E | P | P | P | P |
| Orgganic Titanate | G | G | G | F | F | F |
| Urethane | VG | E | E | E | E | E |
| Polyethylene Imine | VG | G | E | E | P | P |
| Ethylene Acrylic Acid | E | E | F | F | E | G |
| Polyvinylidene Chloride | E | F | E | G | VG | F |

E = Excellent; VG = Very Good; G = Good; F = Fair; P = Poor
Source: TAPPI Manual, “Extrusion Coating of Paper and Paperboard — Equipment and Materias”

and system line speed. Thin substrates and thin coatings require a smooth roller, not a high capacity coater, such as the gravure roller or wire-wound rod. It the line speed is high, a large diameter roller is needed to prevent the primer from being “thrown” by the centrifugal force generated by a smaller roller running at a high speed.

The coating pan, from which the roller picks up primer, should be readily accessible for quick replacement or cleaning. The pan can be replenished either by a pumping system or manually. The pan can be eliminated entirely if reverse angle dual blade applicators are installed **(Figure 20)**. With this device, liquid primer is pumped into the applicator and excess returned to a closed supply tank.

Continuous monitoring systems accurately control primer application. These units work on the principle of infrared spectroscopy, optical reflectance or electron absorbance.

When primer or lacquer is applied to the substrate, the web must pass through a drying tunnel before going to the extrusion coating stage. A volatiles recovery system is essential here to prevent vapors from escaping. Various dryer designs are available, e.g., arch dryers, U-type dryers, counterflow dryers, belt dryers, air-flotation dryers, roller-support dryers and drum dryers.

In these dryers, volatile components of the primer are evaporated by hot air or infrared heaters. Ovens should be equipped with a system for recovering volatiles so none are released to the atmosphere or the extrusion coating shop.

### Flame Treatment

In flame treatment, which is primarily used for heavy paper and paperboard, the substrate is lightly oxidized to enhance its adhesion to the polyolefin extrusion coating. This type of equipment is simple in design, easy to operate and relatively inexpensive. Flame treatment is also said to prevent pinholes, which can occur with an improperly adjusted corona treater.

### Corona Treatment

Corona treatment of plastic substrate involves high voltage, high frequency electricity discharged from an electrode into an ionizing air gap (generally about 0.060 in.), where it passes through the substrate to an

Courtesy of TAPPI

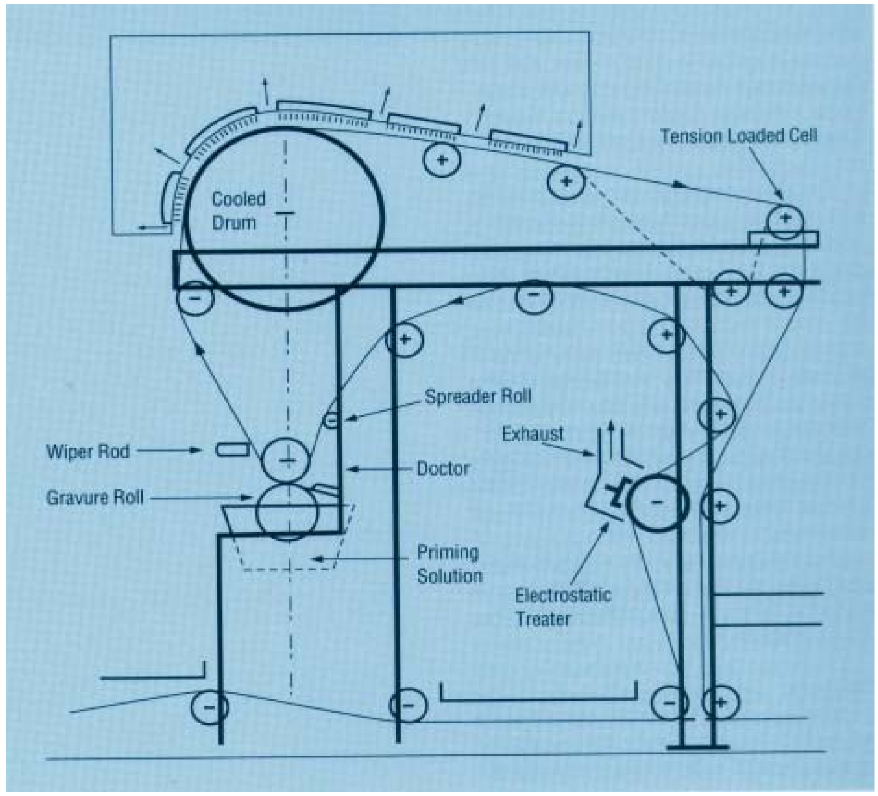


**Figure 19. Chemical Priming Stations**

Courtesy of TAPPI

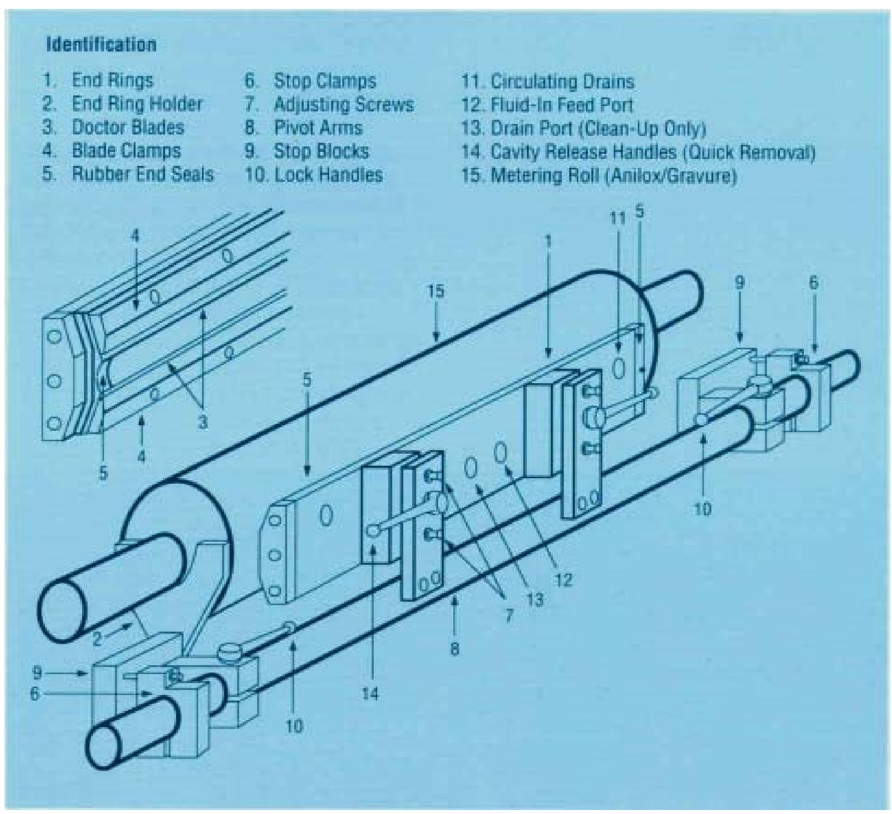


**Figure 20. Reverse Angle Dual Blade Applicatiors for Priming**

Courtesy of TAPPI

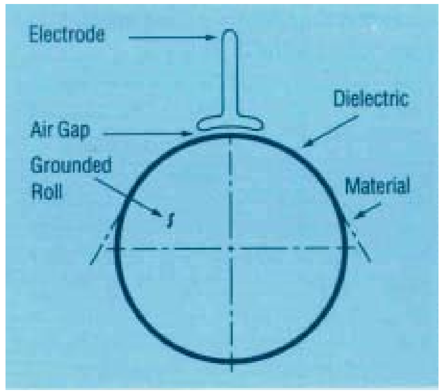


**Figure 21. Corona Treatment**

Courtesy of Black Clawson

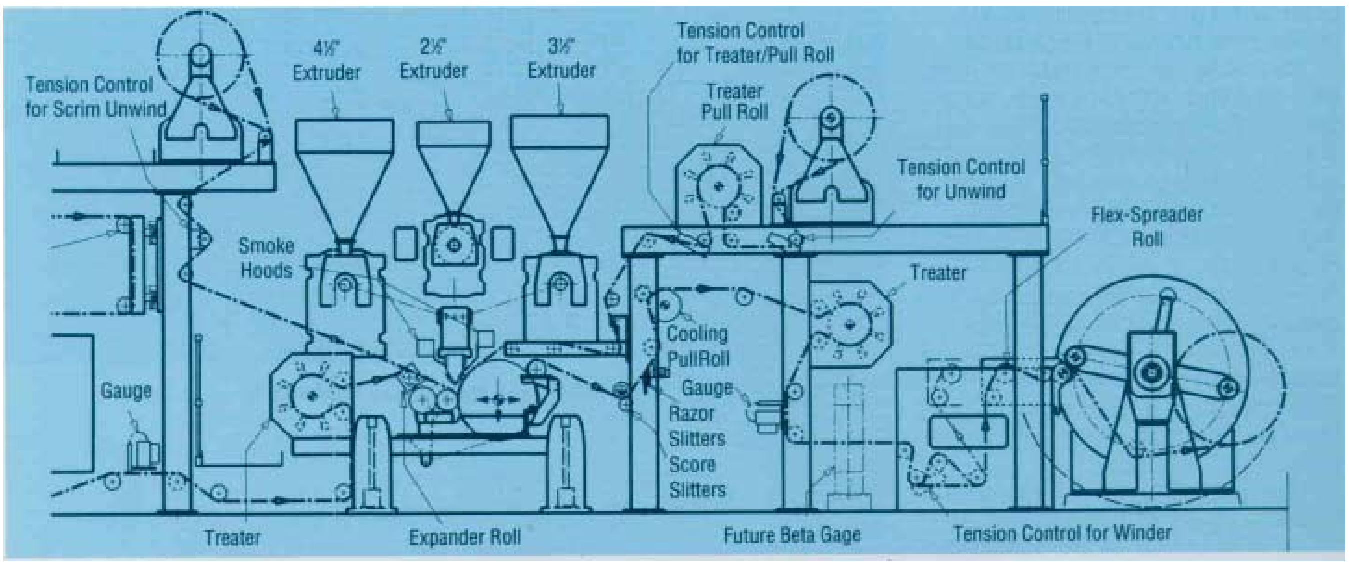


**Figure 22. Coextrusion Coating Line with Bare Roll Corona Pre-treat and Post-treat Stations**

Courtesy of Black Clawson

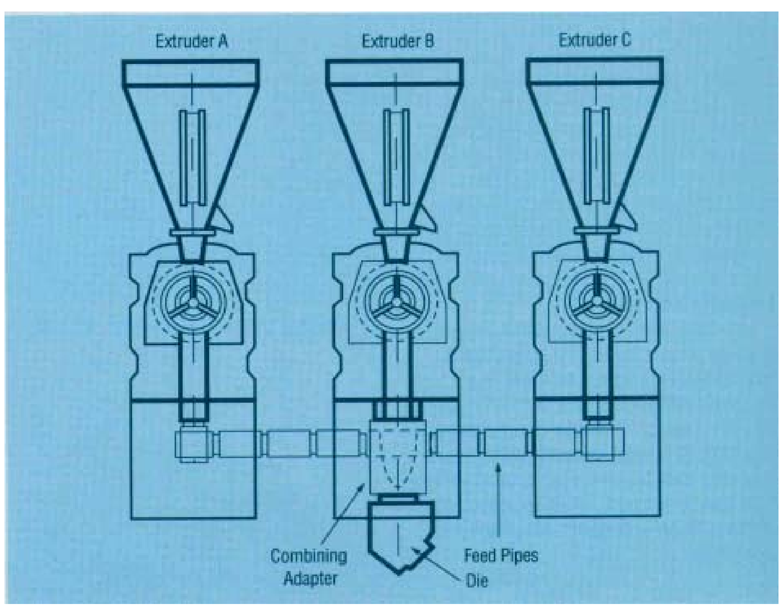


**Figure 23. Multiple Extruders for Coextrusion Coating**

electrically grounded metal roll **(Figure 21)**. This treatment increases the surface tension (measured in dynes/cm) of the substrate to at least 10 dynes/cm higher than the tension of the extrusion coating. A method of measuring the surface tension is the "Wetting Test" (ASTM D 2578).

The power of the corona treater (W/ft²) required to obtain the needed level of surface tension varies with the type of plastic substrate. For LDPE, it can be as low as 0.5 W; for high-slip HDPE or PP, 10 W may be needed.

Two of the more widely used corona treatment electrodes are ceramic and quartz. Ceramic electrodes are particularly effective and durable. The generators used in corona treatment produce high voltage and extreme care must be taken in their operation. Further, corona discharge produces ozone, a corrosive and toxic gas. The treater station, therefore, should be made of materials that withstand ozone, such as stainless steel or aluminum, and proper ventilation systems must be installed to protect workers.

## THE EXTRUSION COATING MACHINE

To coat a substrate with a polyolefin **(Figures 15 and 22),** the resin is first subjected to heat and pressure inside the barrel, or cylinder, of an extruder. The now molten resin is then forced by the extruder screw through the narrow slit of the extrusion coating die. The slit is straight, and thus, melt emerges as thin film.

This molten film is drawn down from the die into the nip between two rolls below the die —-the driven, water-cooled chill roll and a rubber-covered pressure roll. Here, while coming into contact with the faster moving substrate on the rubber-covered pressure roll, hot film is drawn out to the desired thickness, or gauge. The hot film is then forced onto the substrate as both layers are pressed together between the two rolls, Pressure is generally between 50 to 100 lb/linear in. (136 to 271 kPa/linear cm). The combination of substrate and polyolefin coating is then rapidly cooled by the chill roll.

Coextrusion systems designed for making multilayer extrusion coatings have two or more extruders feeding a common die assembly. The number of extruders depends on the number of different materials comprising the coextruded film. For example, a three-layer coextrusion consisting of a barrier material core and two outer layers of the same resin requires only two extruders. A five-layer coextrusion consisting of a top layer of LDPE, a tie-layer resin, a barrier resin, a tie-layer and a EVA copolymer layer, requires four extruders, as the two tie-layers come from the same extruder **(Figure 23)**.

Tie-layers often are used in the coextrusion coating of multiple layer constructions where polymers or other materials would not bond otherwise. The tie-layers are applied between layers of these materials to enable maximum adhesion. Atypical multilayer film construction might be LLDPE/tie-layer/EVOH barrier/tie-layer/EVA.

Courtesy of TAPPI

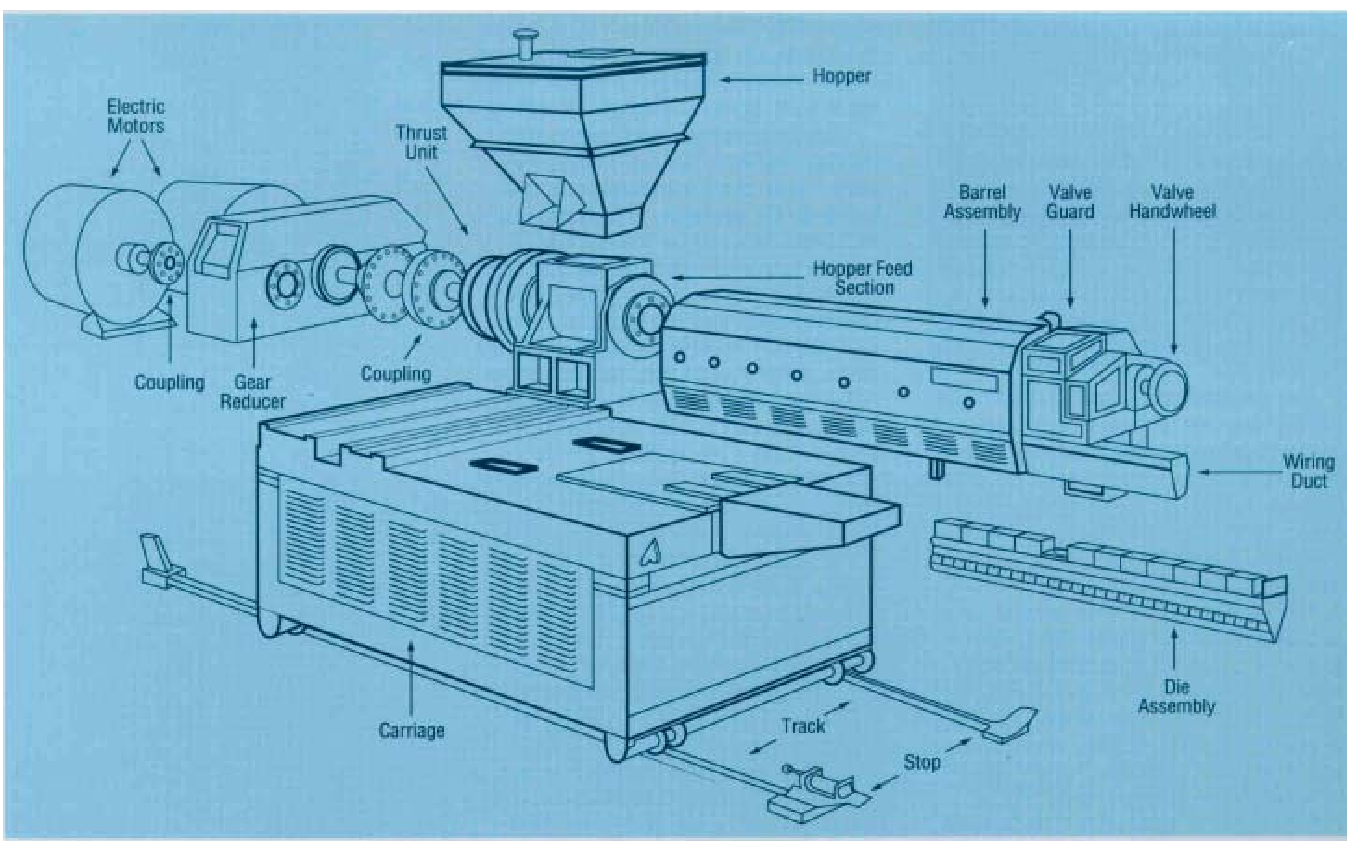


**Figure 24. The Extruder and its Parts**

LyondellBasell produces PLEXAR tie-layer resins designed for use with specific substrates and coatings, e.g., EVOH/BOPP, EVOH/HDPE, EVOH/PS, nylon/PET, etc.

## Hopper

The hopper feeds polyolefin resins into the teed section of the extruder. On top of the hopper, generally there is an automatic loader that periodically feeds the resin into the hopper. Some designs may also have hopper blenders, which can feed and proportion resin, colorants and additives to the extruder. Two types of automatic hopper feeding systems are common:

1. Volumetric feeders refill the hopper on a schedule based on the extrusion system's output.
2. Gravimetric feeders, also referred to as weight-loss feeders, directly teed resin into the extruder feed throat. These feeders weigh materials fed to the extruder from a weigh hopper and determine the rate at which the material is consumed. Gravimetric feeders ensure that the resin in the feed section of the screw remains the same. With volumetric feeders, resin pellets tend to become more compact in the screw area when the hopper is full. If a computer is connected to the system, the actual material consumption rate can be compared against set points specified, statistical analysis performed and adjustments made, as necessary, to maintain specified output. When a deviation is detected, the control system corrects by changing the screw speed.

## Extruder

The extruder **(Figure 24)**, generally the single screw-type, mounted on top of a carriage, consists of:

- A Gear Box
- A Drive Motor
- A Barrel that encloses a constantly turning, flighted auger screw and several heaters (induction or resistance)
- A Cooling System (either water or air) on the outside of the barrel
- Many Thermocouples to measure and control zone temperatures via a control instrument
- A Valved Adapter with a screen pack through which the melt is directed into a flat die
- A Melt Thermocouple and backpressure transducer for indicating process conditions

The extruder drive provides the power needed to rotate the screw. For extrusion coating, a DC SCR (silicon-controlled rectifier) drive is most widely used. The drive power required generally ranges from 5 to 7.5 kW/lb-hr (3 to 4.7 kWkg-hr). A typical 4½-in. diameter extruder has a 200 hp drive; a 6-in. extruder has a 400 hp drive.

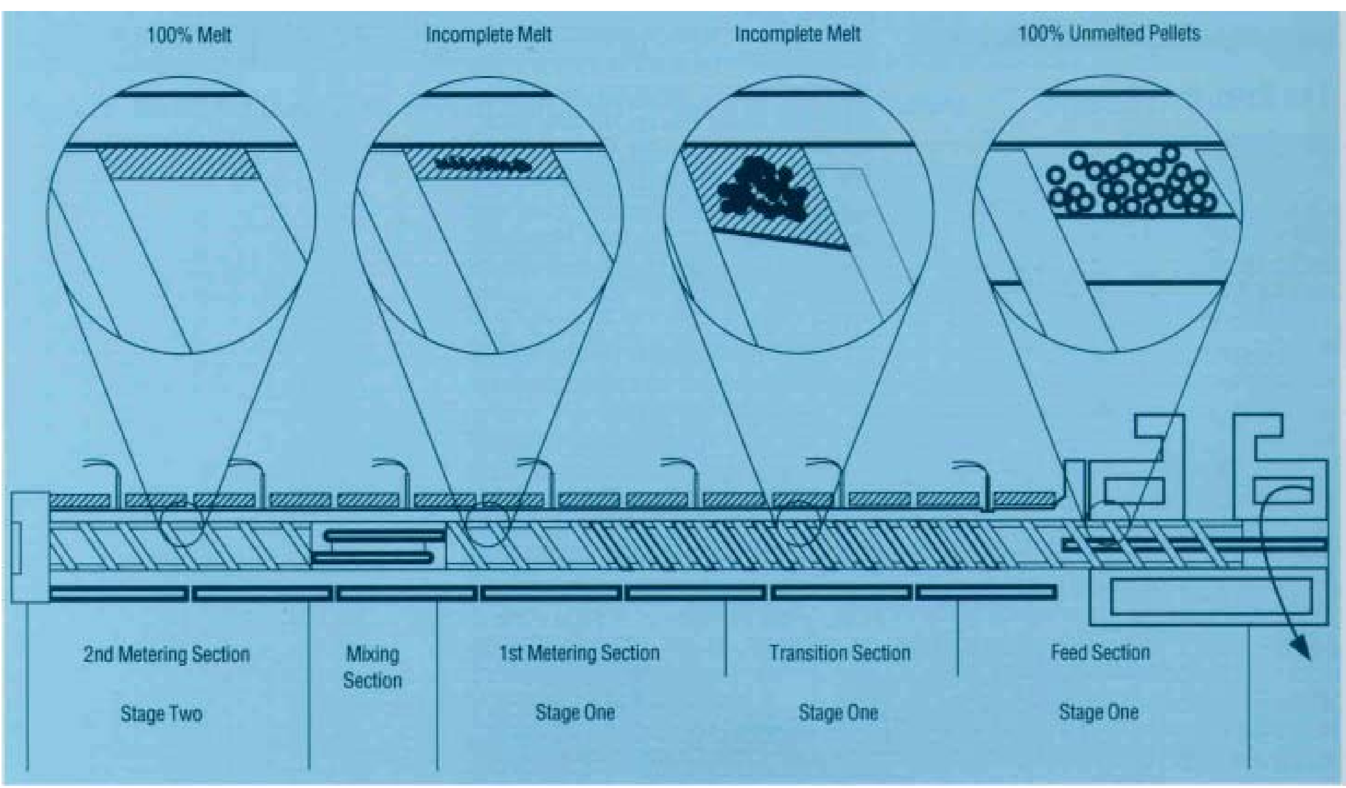


**Figure 25. Extruder Cross Section with Polymer Melting Stages**

The extruder drive provides the power needed to rotate the screw. For extrusion coating, a DC SCR (silicon-controlled rectifier) drive is most widely used. The drive power required generally ranges from 5 to 7.5 kW/lb-hr (3 to 4.7 kWkg-hr). A typical 4½ inch diameter extruder has a 200 hp drive; a 6 inch extruder has a 400 hp drive.

The screw in an extruder rotates at a speed of 5 to 300 rpm, which is far below the maximum output speeds of the drive systems, which can be as high as 1,750 rpm. Therefore, a gear reducer is used to supply the needed torque from the drive. The gearing used is helical, double helical, herringbone or a variation of these three. A typical ratio from drive motor to extruder screw is 7.6:1 for polyethylene extrusion coating.

### Barrel

Extruder barrels are lined with wear-resistant bimetallic liners, such as tungsten carbide. With such liners, the life of the barrel, under continuous use, can range from 5 to 20 years, Generally, the downstream end of the barrel has a rupture tube or disk designed to fail if pressure in the barrel increases beyond a safety limit.

### Heaters

Heat to soften the resin on its way through the barrel is provided internally, by frictional forces from the mixing and compressing action of the screw and externally by heaters. The adapter and die head are also heated to prevent loss of heat from the melt. Band heaters are the most common types of electric heater used. They respond rapidly, are easy to adjust and require minimum maintenance. As shown in **Figure 25**, the heater bands are distributed along the barrel length in zones (typically, there are three to six independent zones, each with its own heating control). About 25 to 45 Watt/in² (4 to 7 Watt/c\m²) of barrel surface gives adequate heat. Resistance heating is usual for electric heaters on extruders, although induction heating is occasionally used.

Each of the independent electrical heating zones are regulated by a controller. A temperature drop in one zone may indicate a defective heater-, a rise may point to a hot spot caused by a damaged screw rubbing on the barrel lining or another problem. Today's modern extruders use computer-aided controllers, which can be programmed for specific applications on the line, to maintain recipes and to print reports.

If the heating capacity of the extruder is inadequate, heaters will be turned on most of the time. To facilitate the detection of heat failure, some extruders are equipped with an alarm system, which warns of heat loss or a blown fuse in the extruder or die. (NOTE: At high output rates, 90% of heat energy should be supplied by the drive and 10% by the barrel heaters for good, uniform melting of the polymer.)

Heater failures occurring during operation may not be detected since the frictional heat generated by the extruder can be sufficient to maintain the operating temperature. When an extruder is shut down, the heat controllers should be checked before starting a new production run.

### Barrel Cooling

Air blowers, located along the barrel length, can be run to lower barrel temperature. Blowers also permit rapid barrel cooling when the extruder is shut down. Air cooling is a maintenance-free system, although water cooling is also used to adjust barrel temperatures. Temperature-control led water circulates through tubes within the heater bands and a heat exchanger removes heat from the water before it is recirculated. Scale build-up and leaks however, often plague this system. Also with water cooling, control solenoids can malfunction, causing temperature zone control problems.

### Thermocouples

Thermocouples, inserted deep into the barrel wall in the various heating zones and in some cases even into the melt, monitor processing temperatures. Temperature controllers receive signals from the thermocouples to regulate the band heaters and cooling devices. Thermocouples should be regularly checked to detect loose fittings and

**Table 6: Functions of the three Sections of a Single-Stage Extrusion Screw**

| Section | Channel Depth | Functions |
|---|---|---|
| **Feed** | **Deep** | **Cool resin pellets are moved forward into hotter barrel zones** |
| **Compression or Transition** | **Decreasing** | **Air carried along slips back to the feed section. Resin is compressed, melted and mixed.** |
| **Metering** | **Shallow** | **Sufficient back pressure is created to make the melt homogeneous (uniform)** |

**Table 7: Common Extruder Sizes and Die Widths**

| Extruder Size | Die Width |
|---|---|
| **3½ in. (89 mm)** | **24 to 48 in. (61 to 122 cm)** |
| **4½ in. (114 mm)** | **36 to 60 in. (91.5 to 152.5 cm)** |
| **6 in. (152 mm)** | **54 to 128 in. (137 to 325 cm)** |
| **8 in. (203 mm)** | **to 160 in. (406.5 cm)** |

other problems. Automatic process controls work only when thermocouples are tightly seated in the barrel wall.

## Screw

The screw rotates within the hardened liner of the barrel. The standard single-stage screw generally has three sections **(Table 6)**. Channel depth is shallower in each progressive section. As the screw rotates, the screw flights force the resin in the channels forward. As the channels become more shallow, the resin is heated, melted, thoroughly mixed and compressed **(Figure 25)**.

Variables in the design of single-stage screws include:

- The pitch of the flight (steady, increasing or decreasing)
- Number of flights per section
- Pitch of the root diameter (constant, tapered or tapered and constant)
- Design of the screw head.

Extruder sizes are designated by their cylinder bore diameter in inches or centimeters. **Table 7** lists extrusion coating die sizes used with the most common extruder sizes.

Extrusion coating lines normally use wide dies and speeds up to 3,000 ft/min. (915 m/min.) to be economical. Large volumes of resin, usually 300 to 3000 lb. (135 to 1,350 kg) commonly pass through the die each hour. Therefore, extruders with large barrel diameters, from 4½ to 8 in. (114 to 203 mm), are generally used.

Screws are specified by their length-to-diameter (UD) ratios and compression ratios. Since higher temperatures are needed for extrusion coating than for any other polyolefin processing technique, extruders used for coating and laminating should have a barrel length-to-diameter ratio of at least 24:1 to provide adequate heating. Generally, 30:1 UD barrels are used today; in some cases, the ratio is as high as 32:1 UD. A long barrel and screw permit:

a. More thorough mixing and therefore, more intensive internal heating of the resin.
b. A greater number of electric heaters for external heating placed along the barrel.

Courtesy of TAPPI

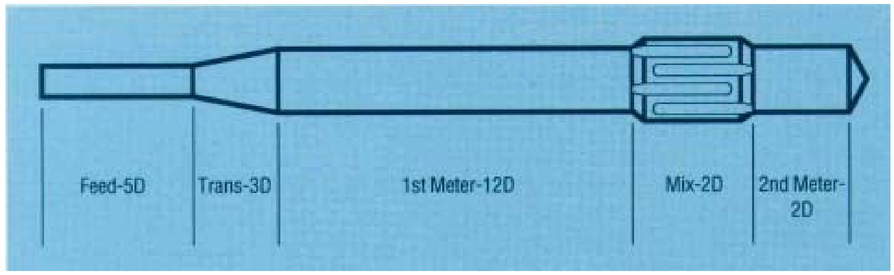


**Figure 26. Mixing Screw**

Courtesy of TAPPI

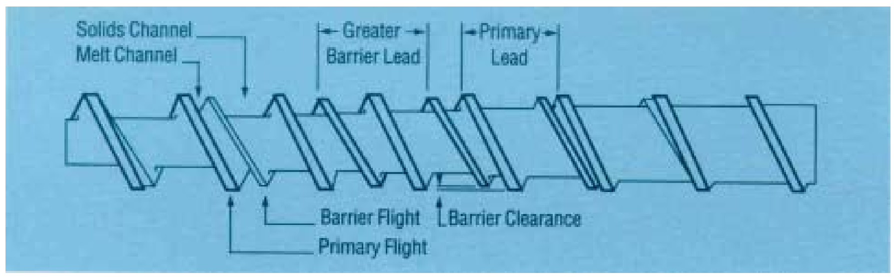


**Figure 27. BarrierScrew**

The compression ratio is the ratio of the channel volume of one screw flight in the feed section to that of one screw flight in the metering section. A compression ratio of about 4:1 is suggested for polyolefin extrusion coating.

High compression forces result in high internal heating and good mixing of the melt. Additionally, these forces efficiently push any traces of air carried forward with the melt back and out through the hopper. Air in the melt can cause bubbles, and at high temperatures, may cause the resin to oxidize in the barrel.

Extruder screws can be cored for water cooling. A cool screw can prevent bridging in the feed section that might be caused by premature melting of the resin. Also, cooling can improve resin mixing, but can reduce output at a given screw speed. Screw temperature is automatically controlled (80° - 180°F; 25° - 80°C) by a temperature controller which adjusts the amount of water flowing through the screw. If the screw overheats, it loses its pumping capacity. Newer screw designs, however, do not use water cooling.

Screws for polyolefin extrusion coating are practically always run “neutral,” i.e., without cooling by water circulating through an axial bore about 4 to 5 flights past the resin feed inlet in the hopper section. However, cooling the screw may make it a little more versatile by increasing its effective compression ratio. Certain extrusion coating resins, such as ionomers and EVA, require screw cooling.

In addition to single-stage screws, there are many multi-stage designs, such as mixing screws **(Figure 26)**. For some materials, such as LLDPE, color additives and HDPE, additional mixing is required. Mixing screws differ from general-purpose screws in that they have an additional mixing section. The mixing section generally has several rows of raised rectangular rods or pins designed for either dispersive or disruptive mixing. Other kinds of mixing screws have two mixing sections: one at the end of the metering section and one at the end of the compression section.

Barrier type screws **(Figure 27)** are another type of multi-stage screw. Also designed for improved mixing, these screws generally have the same three initial sections as general-purpose screws with a dispersive mixing section at the end of the metering section. All barrier screw designs have the same modification: an additional flight, called the barrier flight, in the transitional section of the screw. There are two separate channels in the barrier flight: a solids channel and a melt channel. The more shallow solids channel is located on the pushing side of the barrier flight. The deeper melt channel is located on the trailing edge of the opposite side. The cross-sectional area of the solids channel is uniformly reduced over the length of the barrier section while the melt channel is correspondingly increased. The barrier flight has a radial clearance larger than the clearance of the main flight. This allows the melt in the solids channel to flow over the barrier flight into the melt channel while the solids are retained, unable to pass over the small clearance. This removal of the melt film helps expose more solids to the extruder barrel surface, thus increasing the rate of melting. While barrier screws can offer significant advantages over mixing screws and general purpose screws, their design is based on experiment. Computer models are developed for barrier screws, as they have been for some other types of screws.

### Breaker Plate

After travelling along the screw length, the melt passes through a screen pack and supporting breaker plate and then, through the adapter to the die. The round breaker plate **(Figure 28)** is located between the end of the barrel and the head adapter, usually fitting into both, but sometimes only into the adapter. This fitting ensures that no melt can leak out. The thick plate breaker is pierced by a large number of equally spaced holes, 1/16 to 1/8 in., (1.6 to 3.2 mm) in diameter, and is held in place by a sturdy ring.

A spare breaker plate should always be available in case the one in use breaks or is replaced along with the screen pack. An extra breaker plate may mean less downtime, because the used one does not have to be cleaned before operations can resume.

The screen pack **(Figure 28)**, located in the breaker plate, consists of a number of stainless steel screens. The screen mesh is the number of openings per one inch of screen. The screen pack serves primarily as a filter for foreign matter, although it also improves pigment dispersion if pigment has been added. Higher back pressure in the screw metering zone, which can improve extrusion coating quality but lower output, may be obtained by a pack of many fine screens.

Melt temperature can be raised slightly by using a very heavy screen pack (more or finer screens) which, by increasing pressure, generates additional frictional heat and results in improved coating quality. However, excessive pressures (>2500 psi, but this can vary with the type of resin extruded) may indicate screen packs need to be changed.

There is no “typical” screen pack. Different packs are best suited for different jobs. Fine-meshed (dense) screens should be located between coarse screens, such as a 20-80-20 screen pack. Always use stainless steel screens. Never use copper screens although they cost less. Copper is too soft for such a high-pressure application and may oxidize and contaminate the resin. Extruders with a valved adapter need only use a single screen; a 24 x 110 stainless steel screen is recommended under these conditions.

Automatic screen changers, which have either a continuous screen band or a rotary unit that indexes when exposed sections plug, can be used with extrusion coating machines. The indexing occurs without interrupting the melt flow.

### Pressure Valves

Pressure valves provide control of the barrel pressure, which has a powerful effect on the melt temperature. Pressure valves provide good back pressure control and take this function away from the die design and screen pack arrangement. Two types of pressure valves are common:

Courtesy of Rapidac Machine Co.

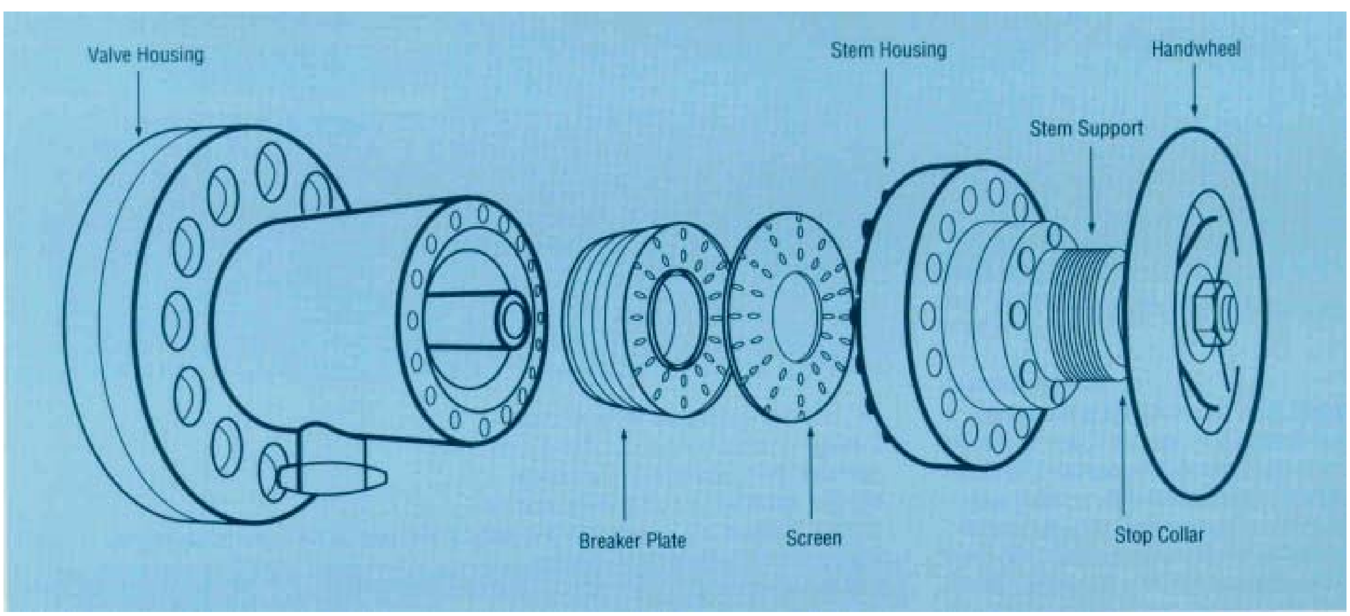


**Figure 28. Valve Assembly**

1. The internal pressure valve **(Figure 29)** is a movable stem that can be adjusted forward or backward to increase or decrease pressure. Moving the valve stem varies the size of the orifice opening between the end of the stem and the polymer flow pipe.
2. Some stems are located on a side of the polymer flow pipe, and pressure is regulated by the land area created by the depth of the stem's insertion into the polymer flow pipe.

### Gear Pumps

Gear pumps **(Figure 30),** also called melt pumps, can be attached between the end of the extruder and the die head to increase melt quality. For continuous multilayer extrusion coating, these pumps can deliver a stable, surge-free melt output and provide excellent layer uniformity. These benefits are particularly important for the extrusion of thin barrier layers and adhesive tie-layers.

### The Die

The extrusion coating die is attached to the valved adapter via a down spout or connecting pipe. A good die design provides smooth melt flow and minimizes the chance that any particles can be held up and overheated. The functions of the die are to:

1. Force the melt into a thin film
2. Maintain the melt at a constant temperature
3. Meter the melt at a constant pressure and rate to the die land for uniform film gauge.

Basic parts of a die include:

- Body
- Mandrel or Jaws
- Heaters
- Lands

The die lands generate resistance to the melt flow and build up backpressure in the die and adapter. If the land length is too short, the melt flow out of the die may be uneven. The die lips, or jaws, can be adjusted to change the die opening to control gauge uniformity **(Table 8)**. Some die designs have as little as 0.098" die land area and have excellent gauge control.

Courtesy of TAPPI

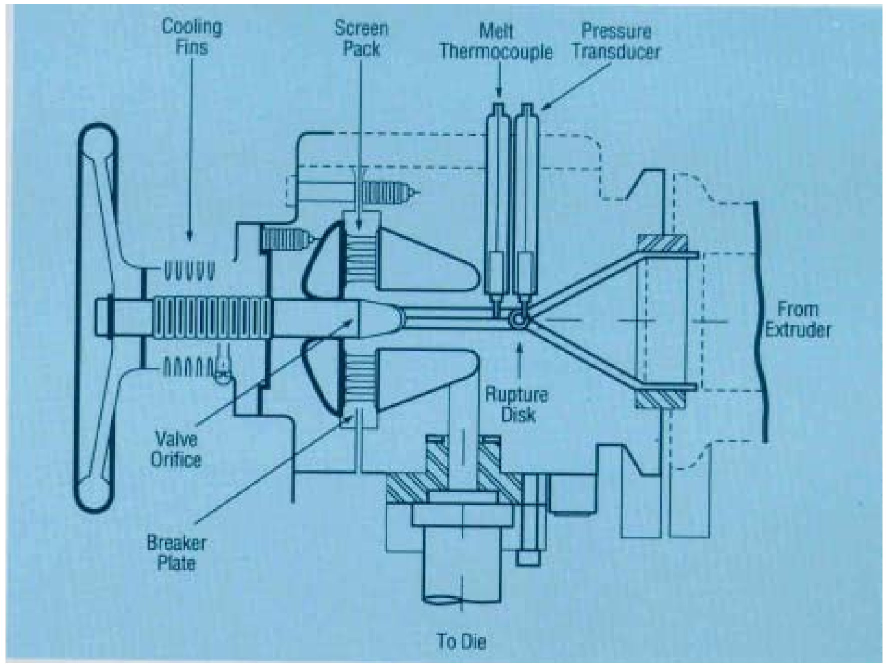


**Figure 29. Pressure Control Valve**

Courtesy of Luwa Corp.

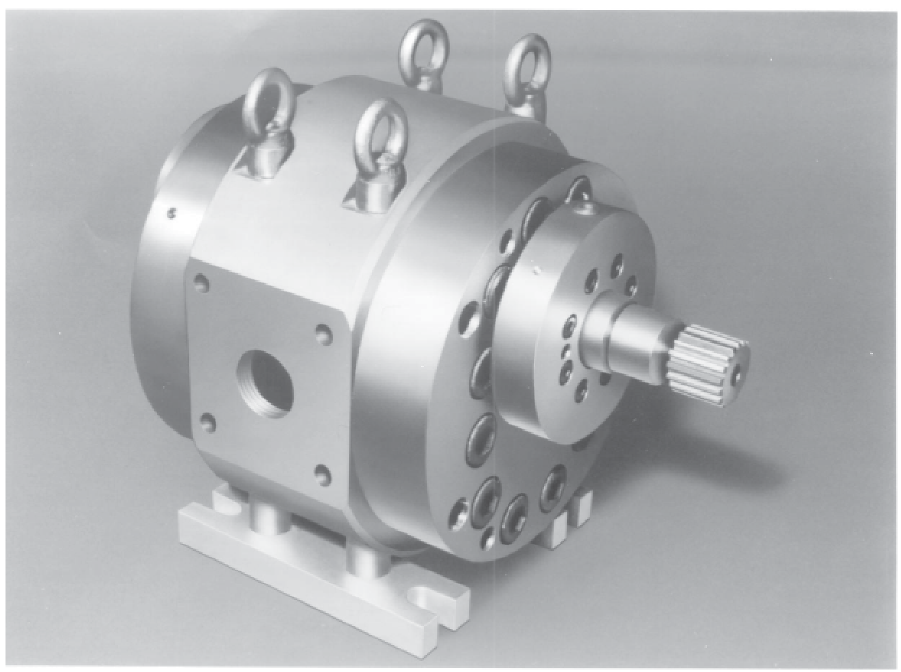

**Figure 30. Gear pumps, also called melt pumps, lead to improved film gauge uniformity by preventing surges in melt output.**

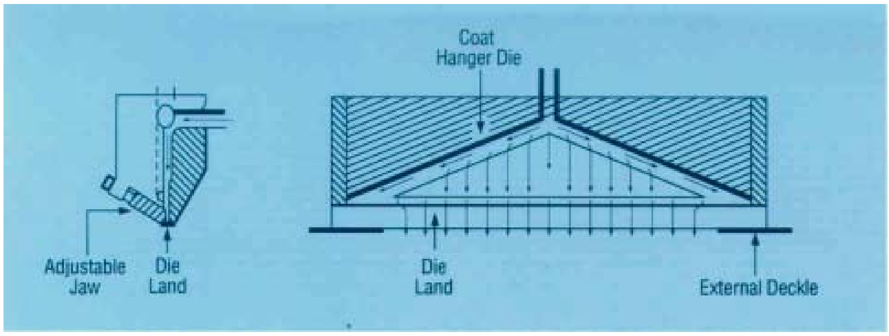


**Figure 31. Schematic cross section on a "coat hanger" type die.**

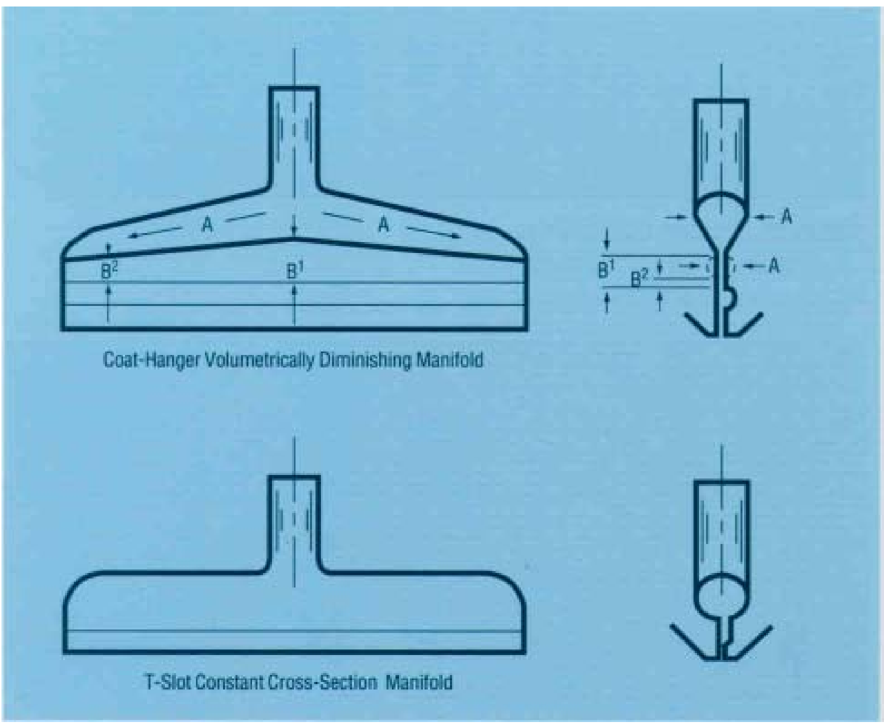


**Figure 32. Coat Hanger and T-Slot Dies**

**Table 8: Recommended Die Gap Openings**

| Die Gap Opening, in. | Coating Weights, lb/ream* |
|---|---|
| 0.020 | <3 |
| 0.030 | 3 - 42 |
| 0.040 | 42 - 70 |
| 0.050 | >70 |

* A Ream = 3,000 $ft^2$

The key is in the machining quality of the die lips.

Die temperature and resin temperature at the die lands (melt temperature) are usually quite high in extrusion coating, up to 625°F (330°C). It is important to keep melt temperatures uniform. An extrusion coating die always has a number of heating zones, each no more than eight inches (20 cm) wide. For uniform coating gauge, the temperature along the die should not vary by more than 2°F (1°C). Die heaters are automatically controlled. For extrusion coating, there are two basic types of die designs:

- "Coat-hanger" dies **(Figure 31)**
- "T-slot" dies **(Figures 32, 32A and 32B)**

In the coat-hanger design, the die manifold, which generally has a teardrop or half teardrop cross section, distributes the incoming melt flow across a steadily widening area. The area ahead of the land streamlines the melt into a film. If this die is "deckled" **(see Deckling Systems, page 22**, the film edge bead is greater than it is with a T-slot die because of the good resin flow to the end of the die from the coat-hanger design.

The T-slot design uses a large volume, circular or teardrop—shaped manifold to minimize melt flow resistance to the die ends. This type of die is normally used with high melt flow resins. With this type of die, the formation of film edge beads is less than it is with "coat-hanger" dies.

With both types of dies, a die lip gives the melt its proper cross-sectional thickness and width. Two basic types of adjustable die lips are common: sliding or flexible. The flexible, adjustable lip (Figure 33) design uses evenly spaced adjustment screws (about one inch apart) across the full die width. The more rigid sliding, adjustable lip **(Figure 34)** also uses evenly spaced adjustment screws, but about two inches apart.

With both the flexible and the sliding adjustable die lips, two basic types of screws are used: "push/pull" or "push-only." The push/pull screw, often used with sliding, adjustable designs, allows the lip to be either forced open or closed. The push-only screw, generally used with the flexible, adjustable lip design, only allows the lip to be closed. To open the lip, the screw

Courtesy of Black Clawson

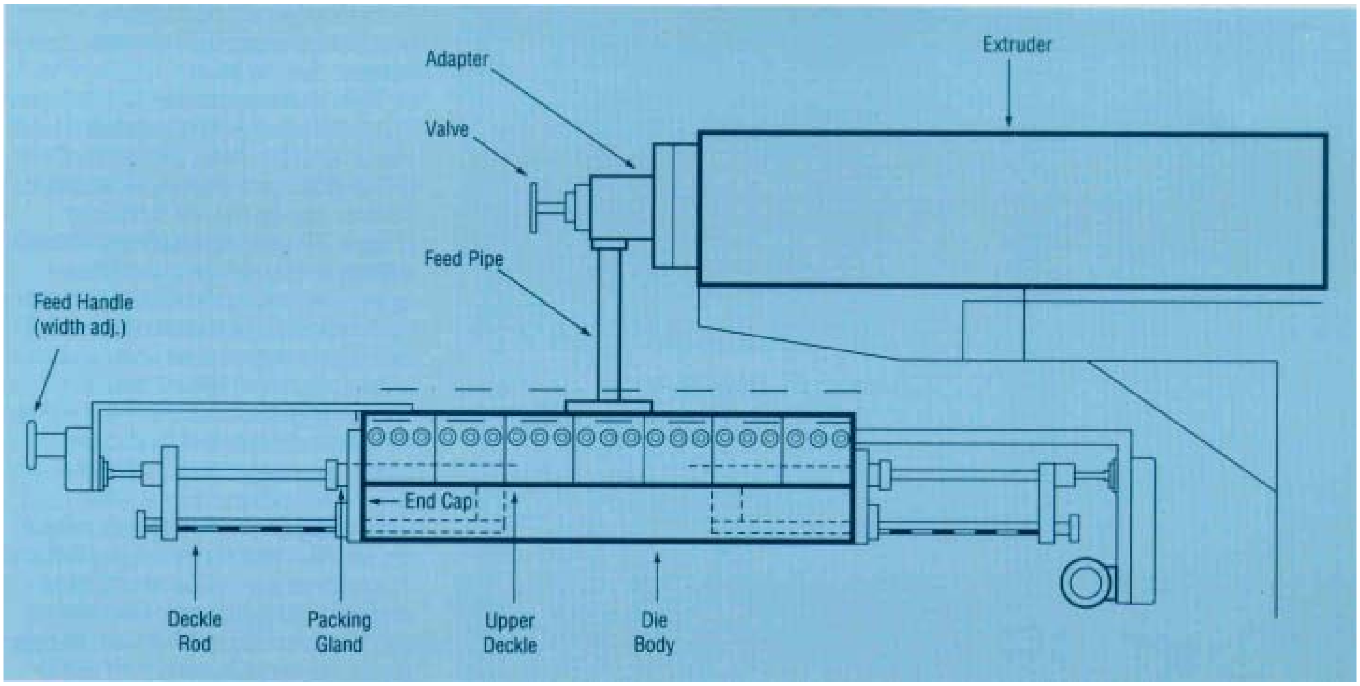


**Figure 32A. "Jyohoku" Edge Bead-Free T-Slot Die**

Courtesy of Black Clawson

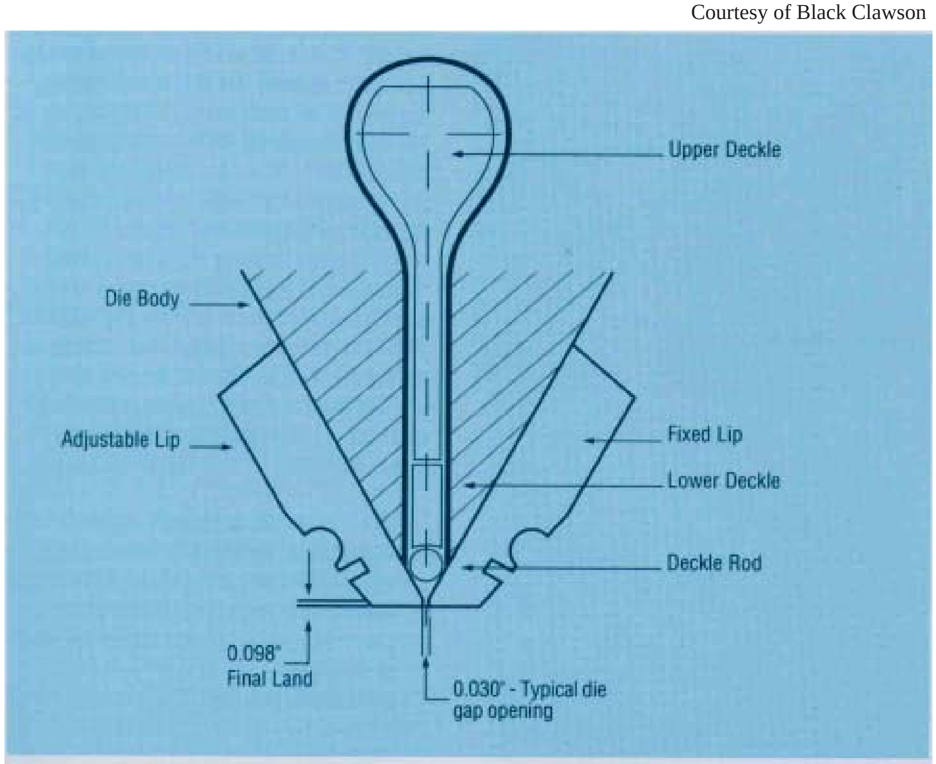


**Figure 32A. "Jyohoku" Edge Bead-Free T-Slot Die**

Courtesy of TAPPI

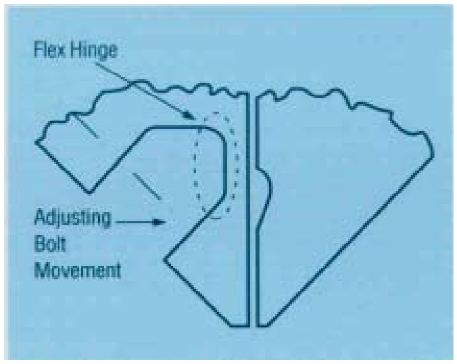


**Figure 33. Flex-Lip Design**

Courtesy of TAPPI

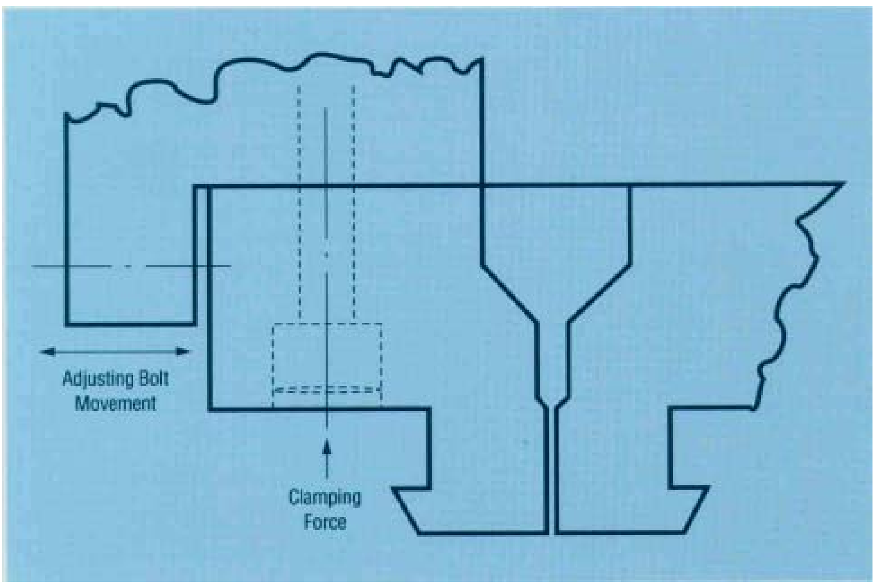


**Figure 34. Fixed-Lip Design**

is backed off, which enables the spring action of the steel lip and the force of the melt to open the die.

The die lip screws can be manually adjusted or automatically controlled. An automatic control includes a microprocessor interfaced with a film gauge sensor. The screws' lengths are thermally expanded or contracted, thus closing or opening the die lip where adjustment is needed.

## Deckling Systems

Extrusion coating die widths may surpass 150 inches. However, increasing die width means increasing system sensitivity. Deckling systems, mechanical devices affixed to both sides of the die lip, can be used to reduce the width of an extrusion coating. Deckling designs include:

- Fixed external, which are not adjustable while the line is running
- Adjustable external, which are usually driven by a rack and pinion gear, permitting adjustment while the line is running
- Adjustable internal

Maintenance is very important when using deckling: resin builds up and oxidizes behind the deckling. Periodically the coating line must be stopped and the die cleaned to eliminate this problem.

To minimize the formation of edge bead when the extrusion coating is applied to the substrate **(Figure 35)**, bead control rods can be attached to the deckling system. The ends of these rods come in contact with the edge of the extruded film to restrict bead formation. Bead formation can be greatly reduced, if not totally eliminated, with a "T-slot" die incorporating a special deckle design with a split inner deckle (upper and lower) and edge control rod **(Figure 36)**.

## Coextrusion Coating

In coextrusion coating, some additional equipment is required, but the result is a sophisticated multilayered package. Coextrusion coating can be an economical alternative to tandem and multi-pass extrusion coating and extrusion lamination. Specifically, coextrusion coating:

- Reduces production time compared to multiple passes and laminations
- Reduces raw material costs
- Improves adhesion between layers because the adhesion layer can be run hotter than the seal layers
- Reduces layer thickness compared to monolayer extrusions
- Maintains melt strength because thinner, lighter layers of individual polymers can compare favorably with an individual monolayer with the same thickness as the sum of the multilayers.
- Eliminates odor by using a reduced melt temperature for the surface layer
- Improves heat seal by decreasing the extrusion temperature of the sealing surface layer
- Improves the strength of the "melt curtain", so that a seal layer and a tie-layer can support a polymer with little melt strength, such as a barrier resin
- Reduces pin holes and improves fracture resistance
- Reduces scrap

## Coextrusion Equipment

Equipment is selected based upon the resins to be used and the structures to be produced. Coextrusion die choices include:

- Dual manifold dies are designed so that the melt curtains combine either internally or externally. Dual manifold dies are usually used when two polymers with great differences in extrusion melt temperature or melt viscosity are to be coextruded. Each side of the die can be separately heated.

Courtesy of TAPPI

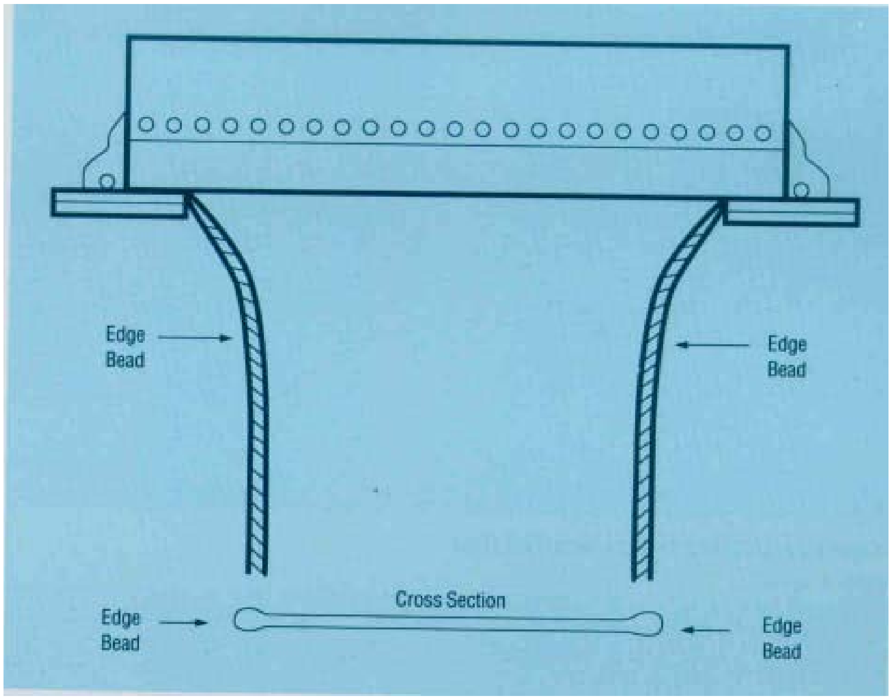


**Figure 35. Edge Beads**

Courtesy of Black Clawson

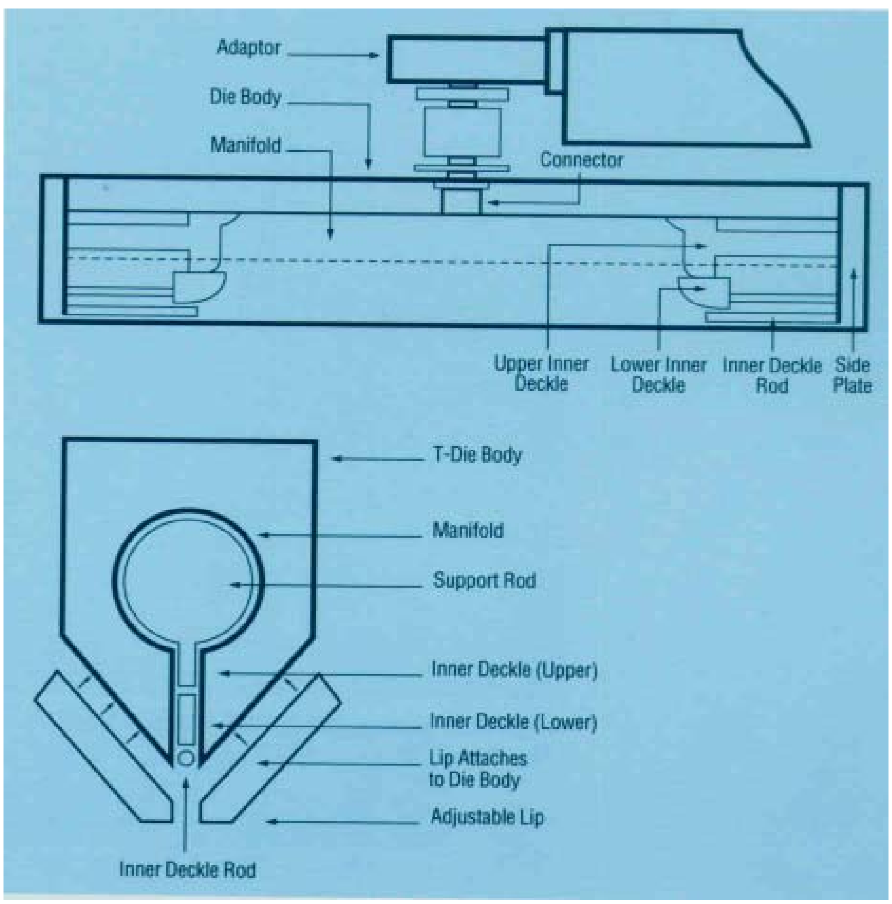


**Figure 36. Bead Reduction Die**

- Dual manifold dies come as single exit dies, which combine the polymer internally just before the exit, or as dual slot dies. Single exit dies, the preferred choice, provide better adhesion and melt curtain draw strength. Dual slot dies are used when the viscosities of the polymers are so different that melt pressure and melt temperature variables prevent an even flow of both curtains from the die lips. Melt curtain surging and melt fractures on the polymer interface can result. With dual slot dies **(Figure 37)**, each layer can be individually adjusted by changing the separate slot die lip adjusting bolts.
- Keyhole dies are often preferred for the extrusion coating of high melt flow resins where many deckle changes are made.
- Coat-hanger dies are used for the extrusion coating of low melt flow (highly viscous) resins, because this die enables better melt flow to its ends. Good flow to the ends of the die can be a problem when high melt flow resins are extruded and when the die has to be deckled-in for narrow web coatings.

### Transfer Piping

Melt flowing from the extruder to a multilayer die or coextrusion combining adapter passes through piping. This piping must be kept as short as possible in length and as large as possible in diameter to minimize its impact on the melt passing through.

### Combining Adapter

The combining adapter is the technology most often used for coextrusion coating. This method can be used with all manifold dies, provided the entrance port is correct for the selected adapter design. The selection of the optimum design for the adapter, as well as for the extruder, valve adapter, feedblocks, feed piping and dies is based upon the rheology of the polymers to be coextruded. Knowledge of rheology and the visoelastic properties of the polymers also optimizes their processability. Contact your polymer supplier for more information about polymer melt flow properties when designing any new coextrusion structure.

Courtesy of Egan Machinery Division, John Brown, Inc.

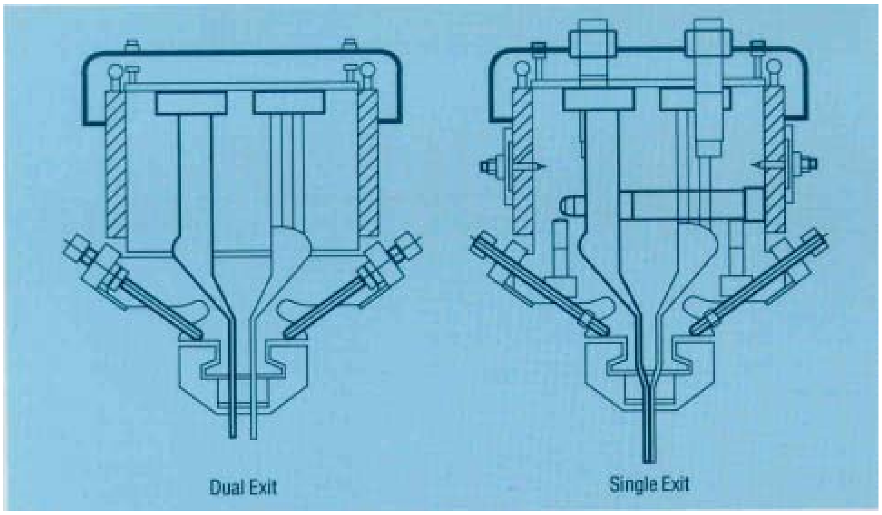


**Figure 37. Designs of Manifold Dies**

Courtesy of Peter Cloren Co., Inc.

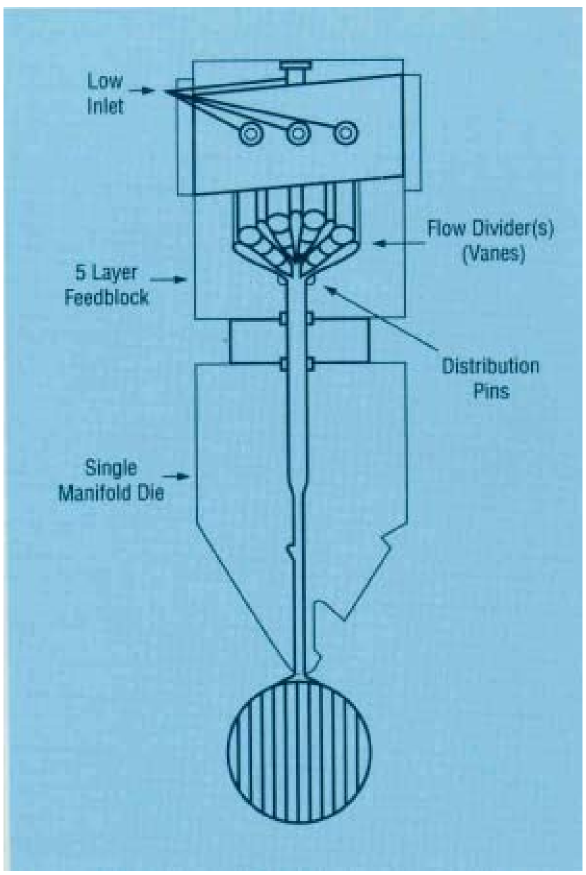


**Figure 38. Coextrusion Coating Feedblock and Monolayer Die**

Courtesy of TAPPI

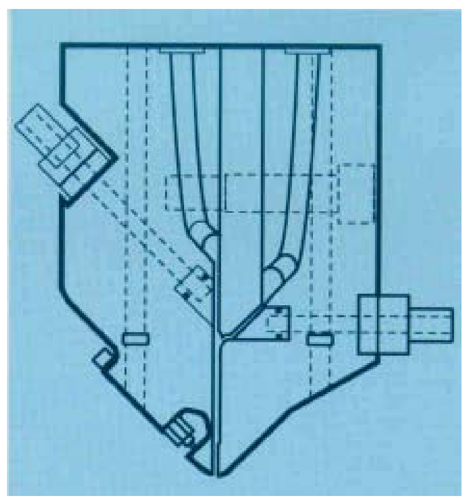

**Figure 39. Multimanifold Die**

### Coextrusion Coating Feedblock

For the extrusion of multilayer extrusion coatings (coextrusions), feedblocks stack melt layers from two or more extruders **(Figure 38)**, based on the principles of polymer melt rheology. The feedblock can be adapted to layer multiplying devices to further increase the number of layers. The multilayered melt stream is then fed to a single-manifold die exit.

### Multimanifold Coextrusion Coating Dies

Multilayer (coextruded) coatings also can be made using multimanifold dies **(Figure 39)**, of which there are many designs on the market. Basically, the multimanifold die has multiple coat-hanger or T-slot dies that feed the different melt streams to either a single or dual flexible, adjustable die lip. This type of coextrusion die is much more complicated than the feedblock type.

## The Coating Rolls

### Pressure Roll

The hot film flowing from the die meets the uncoated substrate as it passes between a pressure roll and a chill roll. For best adhesion, the hot film should contact the substrate just before it reaches the nip that is only ¼ to 3/8 in. (6.5 to 9.5 mm) above-as indicated in **Figure 40**. The pressure roll, a large idler roll with a thick, hard rubber covering, forces the substrate against the extruded coating and eliminates the air between the two layers. Two pneumatically loaded cylinders provide pressure, one on each side of the roll. The hardness of the rubber covering the pressure roll varies according to the substrate being coated. In general, the recommended hardness is 80 to 90 Shore A. If textiles or soft paperboard are the substrate, very hard rubber coverings are used. The pressure roll is mounted such that the nip between it and the chill roll can be opened up more than six inches (15 cm) to make threading substrate during start-up easier. The ability to open the nip quickly and widely is important in an emergency as well.

The design of the coating station is very important. The nip roll must be elevated above the chill roll center line and the back-up pressure roil. This position allows for better clearance of the die relative to the chill roll and the incoming substrate; extends the service life of the fluoropolymer tapes; and increases adhesion to the incoming substrate **(Figure 40)**.

Courtesy of TAPPI

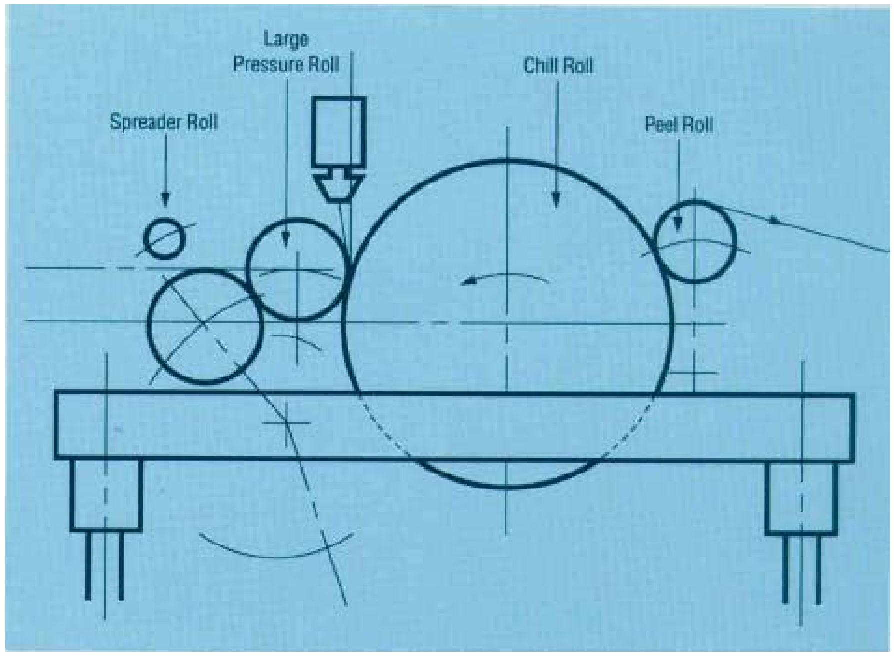


**Figure 40. Coating Station (set air gap range for 5" minimum to 15" maximum)**

**Table 9: Air Gap Opening vs. Coating Line Speed**

| Air Gap, inches | Line Speed, (FPM) |
|---|---|
| 7.0 | up to 700 |
| 8.5 | 700 - 1,200 |
| 10.0 | 1,200 to 1,800 |
| 12.0 | 1,800 and above |

The position of the coating station is adjustable so that the size of the air gap can be changed relative to the die. The air gap size has a decisive influence on the degree of adhesion between the polymer and the substrate. With polyethylene extrusion coating, a rule of thumb Is 11 each one-inch increase in air gap length has the same effect on adhesion as a 10°F increase in melt temperature.

Cooling the pressure roll surface can prevent the hot film from sticking, especially with thin coatings of less than one mil (25 microns). A water-cooled metal idler roll may be run against the pressure roll for this purpose. For some extrusion coating applications, such as fabric coatings, the cooling roll may rotate in a tray filled with cold water. If this set-up is used, a doctor roll or other device prevents water carry-over from the tray onto the substrate. The pressure roll can also be cooled internally. However, the poor heat conductivity of the rubber covering the roll prevents really effective cooling of the surface, but helps the rubber cover adhere to the metal core. Pressure rolls of large coaters may have both external and internal water cooling.

The pressure roll covering sleeve is generally made from a silicone rubber, neoprene rubber, chlorosulfonated polyethylene rubber (Hypalon*) or a fluoropolymer. Unlike neoprene rolls, silicone-covered rolls do not have to be reground after "wrap-arounds" (wrapping of torn, coated substrate around the pressure roll). Silicone-covered rolls are also preferred for very porous substrates, such as cloth, non-woven material or tissue paper and because of their edge-trim release. High temperature substrate preheating also is possible when the pressure roll covering is made from silicone rubber.

On the other hand, silicone rubber coverings are not as hard, resilient or durable as coverings made from neoprene or chlorosulfonated polyethylene rubber. The latter also have good release and can be cleaned easily. Fluoropolymer-covered rolls have the best release of all the types mentioned, but are expensive and difficult to maintain.

**Chill Roll**

The chill roll has three functions:

1. In less than one revolution, it solidifies the coating and cools it to a temperature low enough to permit the coated substrate to be rewound.
2. Its speed controls the coating thickness (or coating weight) by drawing down the melt film from the die. Speed also controls the economy of the extrusion coating process.
3. The chill roll surface determines, to a large degree, the surface smoothness of the coating. If a high-gloss coating is required, the chill roll surface must be highly polished. For a dull coating surface, the chill roll may have a matte finish. The surface of the roll can also be embossed for special effects.

The chill roll is usually a chrome-plated, twin-shell steel drum with an outer shell and an inner body containing spiral grooves for cooling water. Periodically, the rolls must be reconditioned; new, flat, highly polished surfaces applied to the outer surface; and the inner channels cleaned. Some chill roll designs use a replaceable outer shell for quick changes to different surface finishes.

Good alignment of the chill roll, in relation to the failing melt and the pressure roll, is very important **(Figure 41).** Whenever the coated substrate wrinkles, especially in thin-gauge coatings, the position of the die, the lead-in roll, the chill roll or the pressure roll must be carefully adjusted.

A typical system for a closed-circuit chill roll cooling system is shown in **Figure 42**. Chill roll water temperature (68°F in **Figure 41)** ranges between 62° and 80°F (17° to 27°C). The chill roll surface temperature must not exceed 150°F (65°C). The most favorable chill roll cooling water temperature for a given resin and coating speed should be carefully determined and closely monitored, keeping variances less than ± 2°F (1°C).

The chill roll temperature can be adjusted by the flow rate and the

Courtesy of TAPPI

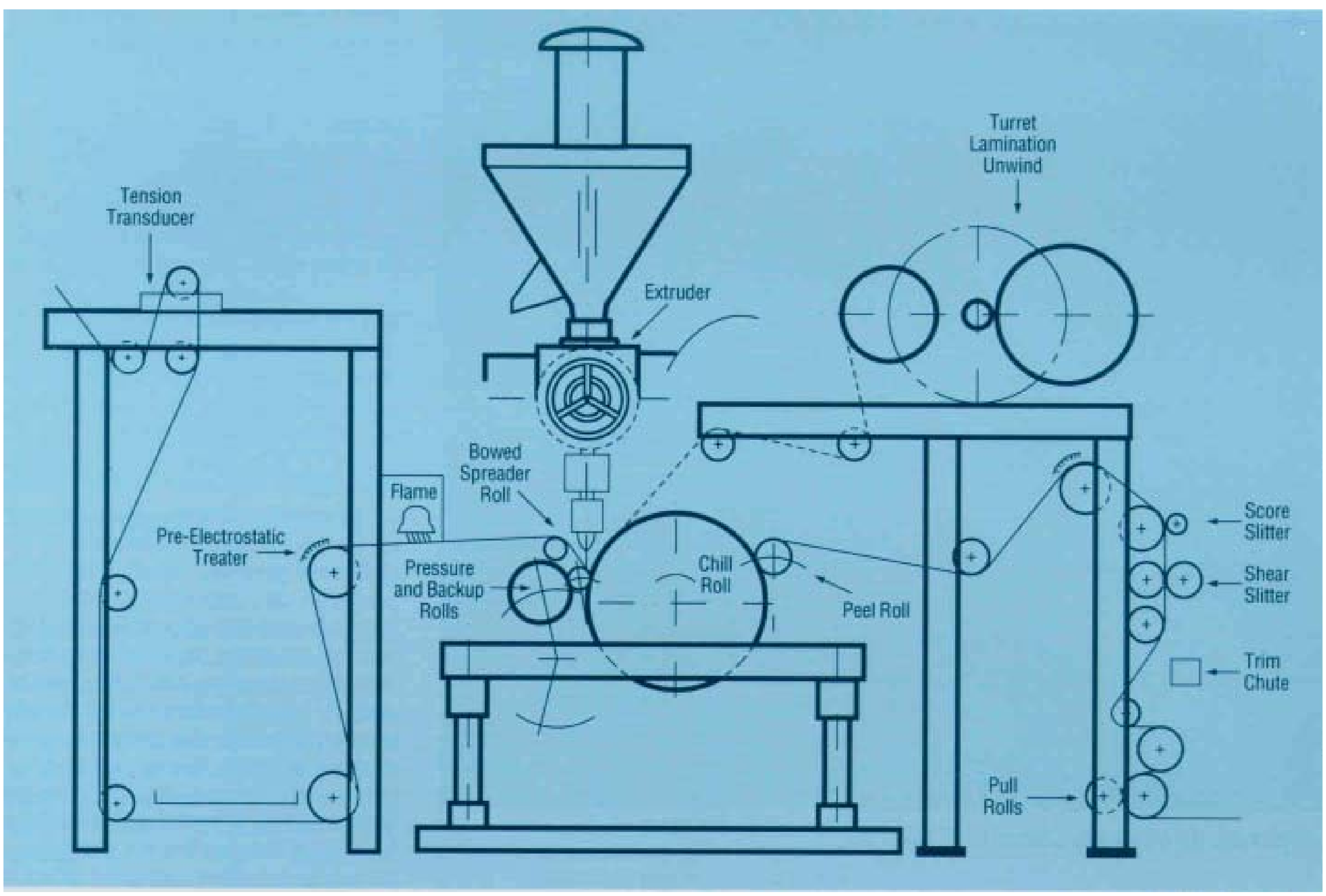


**Figure 41. Extrusion Lamination Machine and Trim Slitting Station**

temperature of the cooling water passing through the roll. A flow rate of 350 gal/min. of cooling water (12 to 15 ft/sec) through the chill roll per 1,000 lb/hr of polyethylene extruded is necessary for good cooling and substrate release.

Condensation can form on chill rolls, particularly when ambient temperatures are well above room temperature, adversely affecting extrusion coating quality. Special, internally-cooled chill rolls which resist condensation even when the roll is stopped are available **(Figure 43)**. This type of chill roll has an internal cylinder with a permanently sealed, capillary wick structure that encloses a heat transfer fluid. Inside the capillary structure, there are channels for cooling water. When the hot film contacts the roll surface, it releases heat that causes the fluid in the capillary system to vaporize. The condensed fluid migrates to the center of the roll by centrifugal force. Here, cooling water absorbs the thermal energy and condenses the vapor. The roll's rotation facilitates the heat transfer.

The coated substrate can be run around two or more chill rolls to lower its temperature. The heat removed by the second, third, etc. roll depends upon take-off speed, melt temperature and the temperature of the first roll. The cooling water temperature of these rolls should gradually reduce the coating's temperature to that desired for windup.

## Peel Roll

A peel roll or stripper roll is required to remove the coated substrate from the chill roll **(Figure 44)**. The location of the peel roll is very important for both proper release and good adhesion. The peel roll should be placed as close to the chill roll as possible, only 0.5 to 1 inch away for a hard-surface roll and directly touching the chill roll if a release cover, such as silicone or fluoropolymer rubber, is used. However, the peel roll must be positioned ("a" to "b" in **Figure 44)** far enough away so that the chill roll surface temperature decreases before it passes again through the coating nip. If the chill roll surface does not cool adequately, line speeds can not be maintained. Also, poor adhesion may result under these conditions as the polymer may stick to the chill roll and pull away from the substrate.

Courtesy of TAPPI

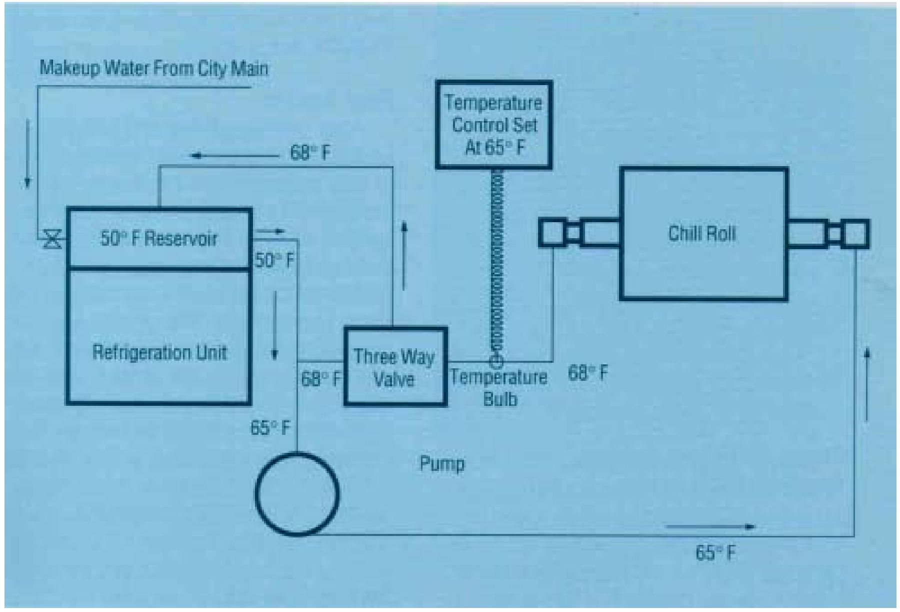


**Figure 42. Closed Circuit Chill Roll Cooking System**

Courtesy of TAPPI

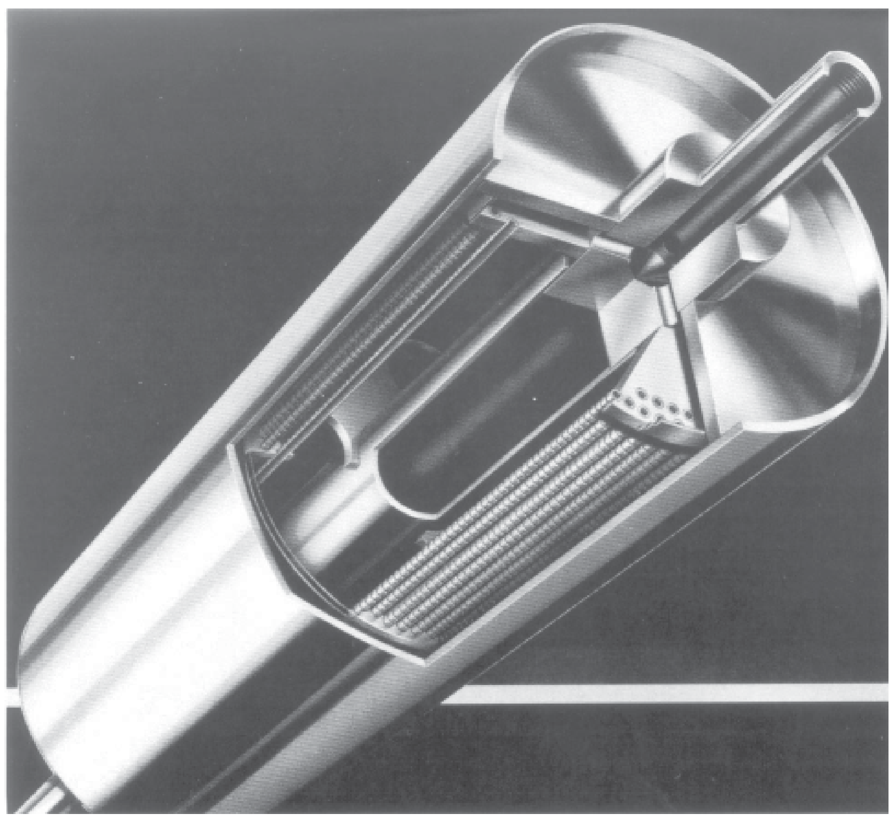

**Figure 43. An Internally Cooled Chill Roll**

## Feed Rollers

After coming off the chill roll, the coated substrate passes through a series of feed rollers before it is wound up by the take-off equipment. In addition to guiding the web to post-coating operations and maintaining proper web tension, these rollers perform other functions. For example, rollers with a herringbone pattern ingrained on them can laterally spread the coated substrate and remove wrinkles; rollers with circular grooves can remove surface air flowing along with the web; pivoting or steering rollers can realign the web; and slightly bowed rollers can laterally tighten the web.

## Surface Treaters

If polyolefin-coated surfaces are to be printed or an adhesive applied, they first must be treated. Electronic treatment is preferred. Ink and adhesive do not adhere to untreated polyolefin surfaces. Treatment is best done in-line, i.e., within the extrusion coating set-up. A treatment station between the chill roll and the slitter roll or right after the trimming step is common. When polyolefins contain slip or antiblock additives, treatment must take place in-line before the additive "blooms" to the surface of the coating.

## Edge Bead Trim Slitters

As the polyolefin melt leaves the extrusion coating slot die and is drawn down in thickness from about 20 to 30 mils to about one mil, the width of the molten web also narrows. This phenomenon is called "neck-in." The amount of neck-in depends on:

- Grade of resin extruded
- Speed of the operation
- Temperature of the melt
- Length of the air gap

With neck-in, a bead usually forms at the edge of the web, thicker than the average coating thickness across the web. The amount of beading depends upon the coating thickness relative to the thickness of the substrate. Lightweight coatings on thick substrates are not as susceptible to beading as are heavyweight coatings on thin substrates. In most cases, this bead must be trimmed off before the web is rewound. The build-up of edge beading can cause flared edges on the rolls, to the extent that the edges tear. Consequently, most extrusion coaters have trim slitters between the coating unit and the rewinder **(Figure 45)**. The three most common types of slitters are:

1. Score cutters, consisting of a hardened wheel with a V-shaped edge that is pressed against a hardened-steel backing roll. The web passes between the wheel and the roll.
2. Shear slitters, consisting of a pair of driven, overlapping sharpened or beveled blades in a scissors-type arrangement.
3. Razor blade slitters, consisting of disposable razor blades positioned against the moving web as it passes either between two closely spaced idler rolls or against a grooved back-up roll.

The type of slitter used depends on the type of substrate coated. Score slitters are often used for film, cellophane, paper and foil laminates. Shear slitters are used on paper board and heavy paper. Trim from the slitters is usually carried away in an air stream via a suction manifold located near the slitter station. The velocity of the air in the trim manifolds must be greater than

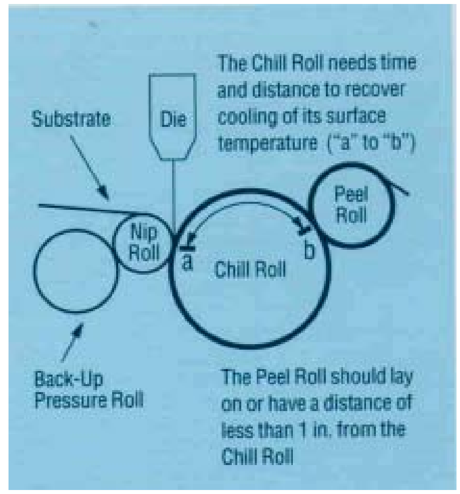


**Figure 44. Proper Cooling Recovery Set-Up**

Courtesy of TAPPI

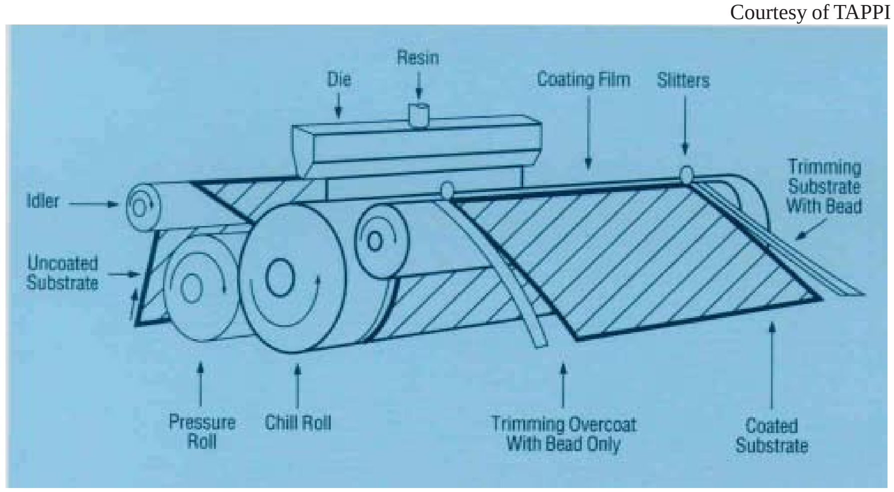


**Figure 45. Edge Bead Trim Slitters**

Courtesy of Exair

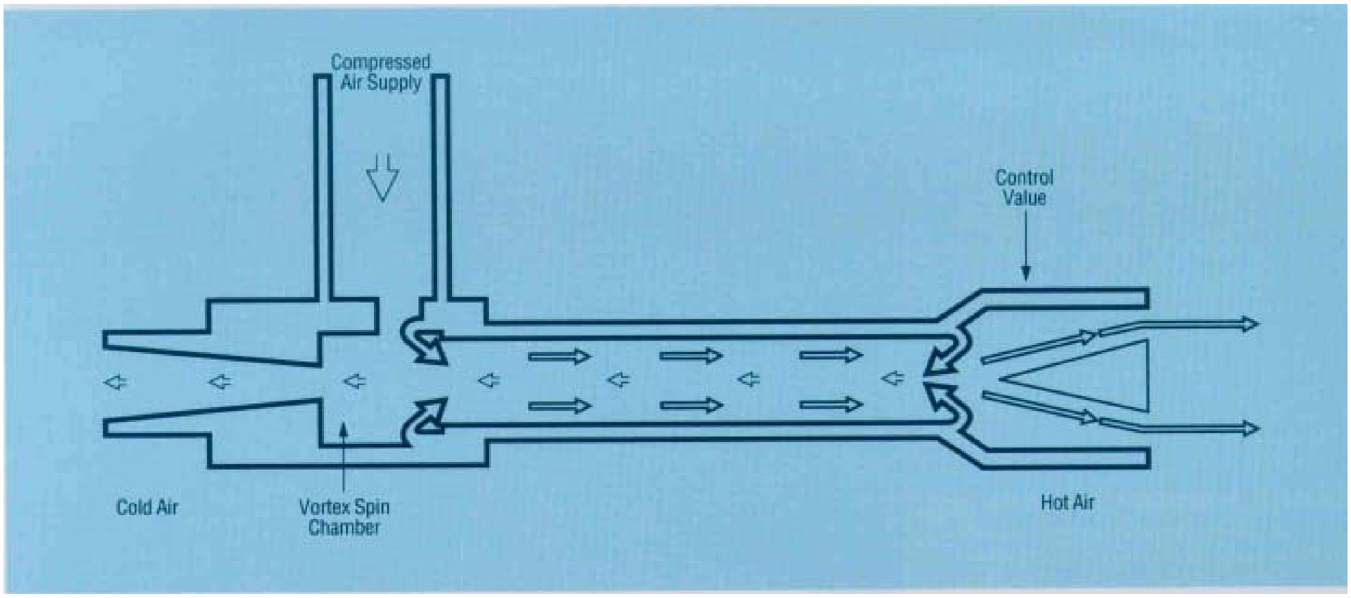


**Figure 46. Vortex Cooling Needle**

Courtesy of TAPPI

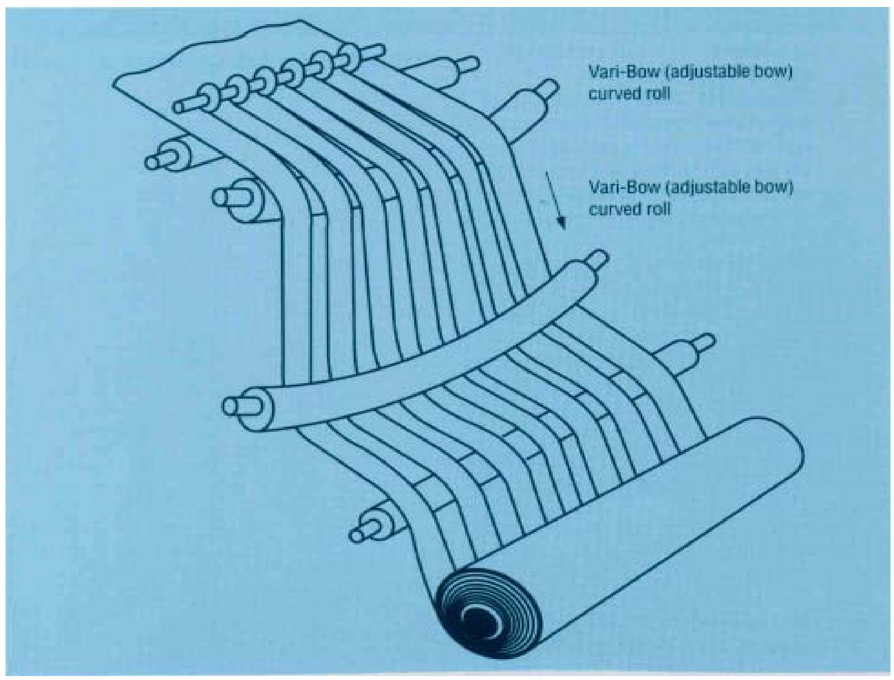


**Figure 47. Slitting the Web**

the line speed of the coater.
If an “overcoat” of polyolefin is applied to the substrate, i.e., the coating extends past the edges of the substrate, the excess coating adheres to the pressure roll. Fluoropolymer tape is sometimes used to mask the pressure roll at the edges of the substrate. A few precautions are necessary for best results. When line speeds are very low and the pressure roll is warming up, as occurs when rolls are changed on the unwind stand, the “overcoat” may stick to the fluoropolymer tape.

Silicone grease or spray may be used in extrusion coating as a release agent at start-up to prevent the polymer from adhering to the nip roll. However, it is recommended that silicone materials be eliminated from extrusion coating. Silicone cannot be used if the reverse side of the substrate is also to be coated, since the silicone will prevent adhesion on the edge of the second coating. Silicone should not be used when the coated substrate is to be used for packaging food products. [NOTE: Silicone should only be used as a last resort since it can cause problems which outweigh the benefits.]

A better solution is to use Vortex Tube Air Jets, which blow cold air at the bottom of the pressure roll (nip roll) to cool the fluoropolymer tape. This cooling prevents the edge bead from adhering to the tape and increases the life of the tape **(Figure 46).**

The fluoropolymer tape must be replaced periodically because of blistering. An operator normally can change the two tapes on the pressure roll in a few minutes, so there is little loss of production time when the substrate width is changed. Some extrusion coating lines use fluoropolymer belts that can be replaced even more quickly.

When substrates less than 10 mill (0.25 mm) thick are coated, the fluoropolymer tape may mark or imprint the coating. To prevent this, place the tape on the pressure roll so that it comes just inside the edges of the substrate for no more than 0.125 inch. Handling this kind of material obviously requires superior edge guiding.

An undercut pressure roll is one that is recessed exactly to the edge of the substrate so that the hot polyolefin bead does not stick to the roll. Using undercut pressure rolls means that a separate pressure roll for each substrate width must be readily available, and production runs must be long enough to make this technique economical.

A single coated web also may be slit into two or more separate webs **(Figure 41 and 47).** After slitting, the substrate passes over a series of bowed rollers that separate the webs slightly before they are wound up.

**Recycling System**

The edge trim from the extrusion coating operation is conveyed from the coater through pneumatic trim disposal tubes to a granulator **(Figure 48).** If the trim is substrate-free, i.e., it is only polyolefin film, it may be sold as scrap. It should not be reused in extrusion coating because changes in the polymer properties as well as processing characteristics such as gels, neck-in, draw-down, odor, etc., are likely.

Courtesy of TAPPI

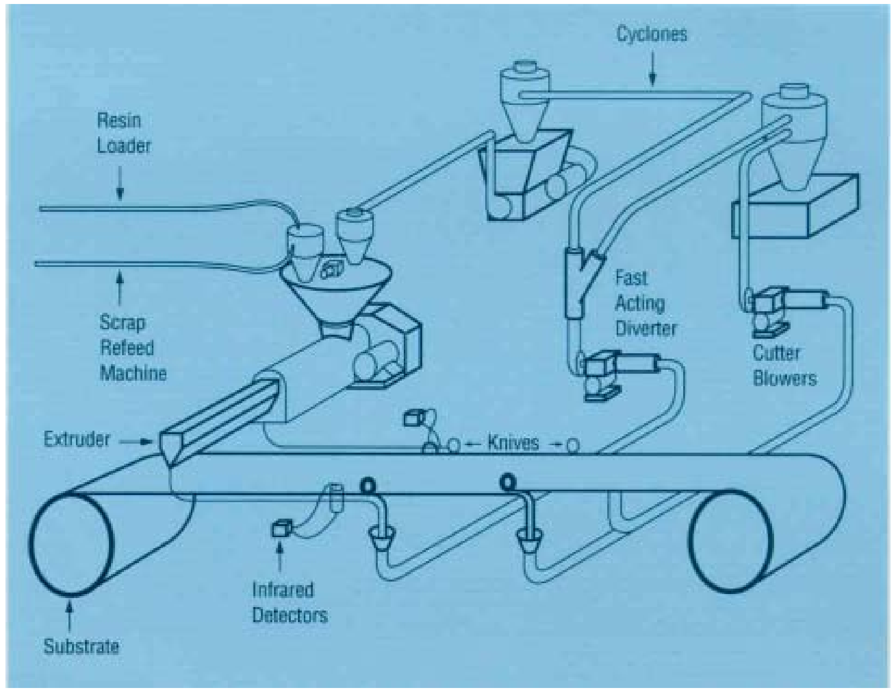


**Figure 48. Extrusion Coating Scrap Recycle System**

## Coating Weight/Thickness Monitors

Two types of devices are used to measure coating weights:

- Nuclear sensors
- Infrared sensors

Nuclear sensors are usually located just ahead of the point where the substrate passes into the coating station and where the coated web moves to the windup equipment **(Figure 49).** Nuclear gauges, also called “beta gauges,” measure the net coating weight on the substrate by focusing a beam of radiation through the web and onto a detector. The radiation absorbed by the web is inversely related to the weight per unit of web. Since the measurements are taken both before (base) and after (gross) coating, it is possible to determine the net coating weight (thickness).

The location of the two nuclear sensors and the interval between readings must be carefully coordinated so that the sensors measure the same area on the web. The nuclear sensor readings can be used to adjust the die opening manually or automatically.

Infrared (IR) sensors operate on the principle that all materials have their own characteristic absorption bands in the near-infrared spectrum. The IR units function in one of two modes:

Courtesy of TAPPI

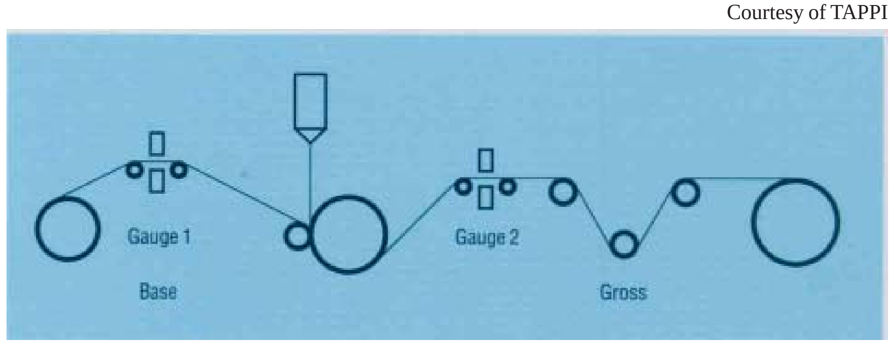


**Figure 49. Coating Weight and Thickness Monitors**

- Transmission: the signals pass through a transparent web to a detector
- Reflectance: the signals rebound off an opaque web and into a detector.

Two wavelength measurements generally are used: a reference wavelength that is not absorbed by the web; and a measurement wavelength that is absorbed by the web. The detector measures the signals and forms a ratio proportional to the weight of the web.

IR measuring equipment is simpler to operate and less expensive than nuclear sensors and it also can measure multilayer materials. However, pigments can adversely affect IR readings (black pigment totally absorbs the near-IR spectrum and white pigment, i.e., titanium dioxide, has a scattering effect). A matte finish also can diffuse the IR beam. Different substrates can yield different IR readings. These disadvantages of near-IR sensors can be minimized by using full-spectrum infrared (FSIR) measuring devices instead.

Both nuclear and infrared sensors should be built so that no ionizing radiation or infrared radiation reaches the operator.

## Takeoff and Windup Equipment

The extrusion coated substrate usually is wound tightly onto a cardboard tube, called a core although metal cores also are used. The core is turned by a winder. Full coated substrate rolls are replaced by empty cores without interruption if multiple windup stations are available.

### Winders

Winders are characterized by:

- The type of take-up roll drive: surface, center or center/surface assist
- The type of roll changing: manual, semi-automatic or fully automatic
- The type of roll stand configuration stacked, face-to-face or back-to-back.

Some winders run shaftless and the web is wound directly on the core. However, most commercial extrusion coating winders have air shafts to inflate rubber bladders attached to expandable metal shafts that fit inside the cardboard cores. The air-supported metal shaft permits different core diameters to be used and enables the core to resist the pressure of the web winding. This second benefit is particularly important when separate web widths are wound on a common core without interleaving. A lay-on roll often is part of this take-off assembly along with a pneumatically-actuated slitting knife for cutting the web into two or more narrower webs.

Surface winders **(Figure 50)** have a driven drum that fits flush against the face of the windup roll. Several surface winder configurations are available, but basically their operation is the same: the rotating drum forces the roll to turn and thus, wind up the web. The roll is held against the rotating drum by gravity or pneumatically. The web remains in uniform contact with the drum by means of a tensioning device. A lay-on roll forces air out from under the web as it is drawn onto the roll. Surface winders are often used when roll diameters exceed 40 inches, but not all polyolefin coatings are handled best by surface winding.

In center winders **(Figure 51),** torque is applied directly to the windup roll shaft. To keep tension constant, a center winder must slow down at a rate inversely proportional to the constantly increasing diameter of the roll. Many center winders incorporate lay-on rolls to force air out from under the web or to ensure optimum flat contact. Rolls of extrusion coated substrate, wrapped

Courtesy of TAPPI

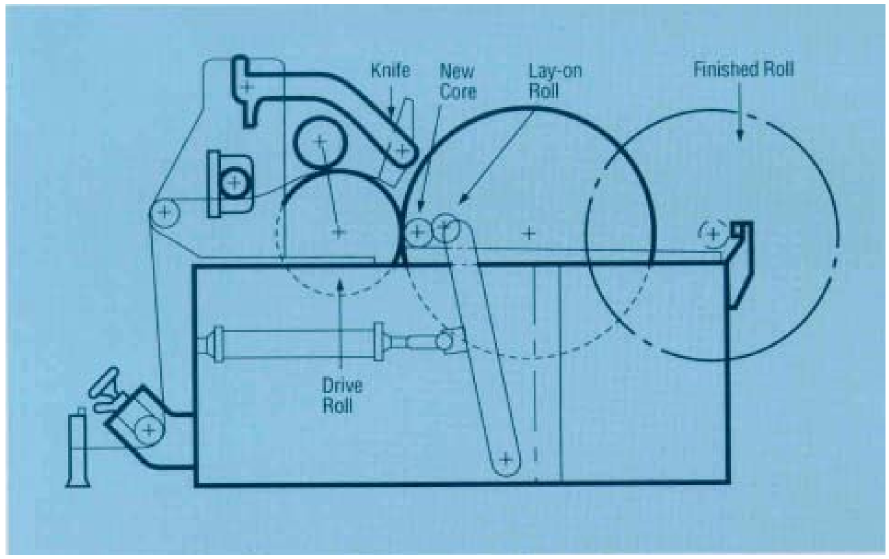


**Figure 50. Single Drum Winder Automatic Transfer**

Courtesy of TAPPI

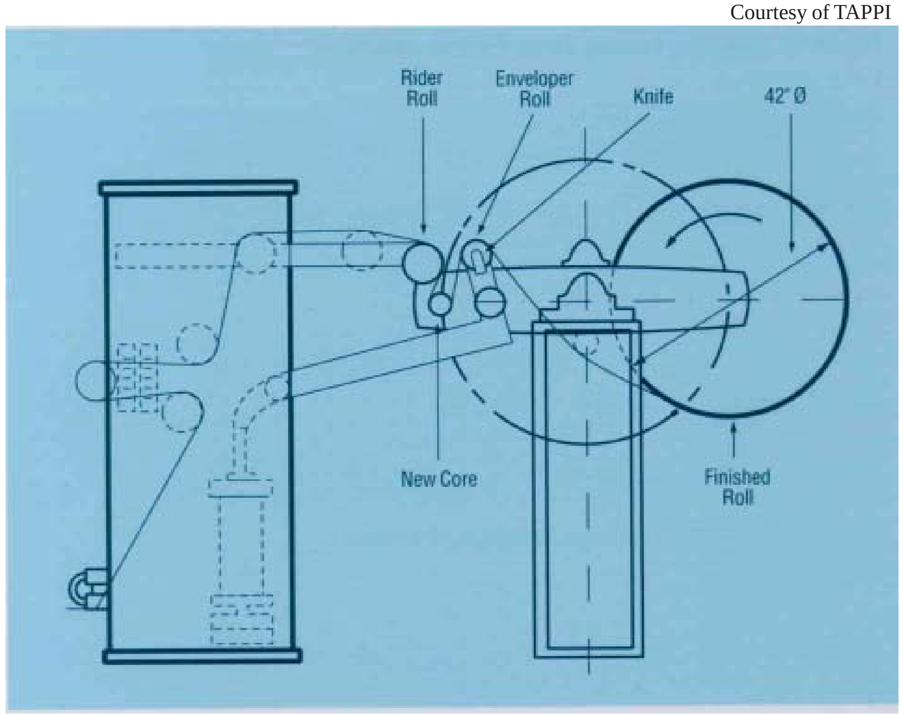


**Figure 51. Center Winder**

Courtesy of TAPPI

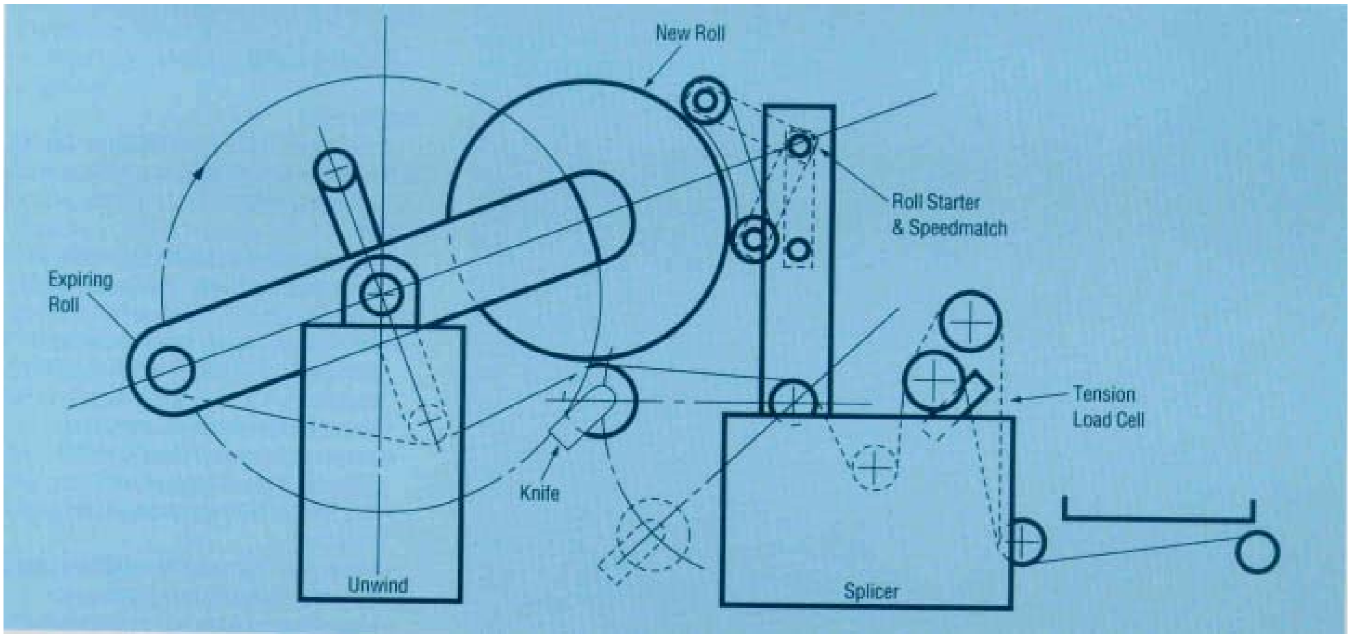


**Figure 52. Flying Splice System Unwind**

onto cores held by chucks inserted in both ends, are formed under constant tension.

Surface or center assist winders have center drives added to the shaft of a surface winder. This type of winder separates winding tension from web positioning requirements and roll hardness.

Gap winding, or proximity winding, is a modification of the center winding technique that is especially effective for tacky polyolefin coatings. An air gap of about a 0.25 inch is maintained between the surface roll and the building roll. Each roll has a tension-controlled drive. As the web builds up on the roll, this roll is gradually moved away.

Taper tensioning, a gradual reduction of web tension, generally is used when the ratio of the final roll is greater than six times the diameter of the core (the “build-up ratio”). In taper tensioning, the dancer roll assembly or the strain gauge roll is controlled. For extensible or soft polyolefin coated webs, taper tensioning eliminates roll defects such as crowning and wrinkling.

The flying-splice unwind, used for continuous long runs **(Figure 52)**, calls for large unwind rolls of many thousands of linear feet of coated substrate. The diameter of a finished roll is many times that of its core. As the roll builds up in diameter, its rotational speed must be reduced because the linear speed of the coated substrate coming from the coater remains the same. For splicing at the rewind, glue or tape is generally used, just as it was at the unwind.

Edge-guide equipment is essential when a flying-splice set-up is used at the unwind station. Either mechanical, pneumatic or photo-electric sensing elements are placed at the edges of the substrate. Whenever the web moves out of line, the sensing elements actuate a device that adjusts the position of the web. A similar set-up is sometimes used to detect breaks in the substrate, sound an alarm and simultaneously open the nip to prevent damage to the pressure roll by the hot melt.

Automatic roll changers deflate air shafts, remove the full roll, place the roll on a cart or the floor, install empty cores into the ready position and inflate the bladders in the metal shafts. Roll changers are particularly useful for high-speed applications that require relatively small roll diameters.

Turret winders are designed to rotate a full roll away from the lay-on roll and index a new core into the winding position. With automatic turret winders, the spindles are separately motor-driven to match the speed required for the automatic cutoff of the web at high speeds.

## Controls

Many elements affect production and quality in an extrusion coating system. Microcomputer controls answer the complex problem of controlling the many variables involved **(Figure 53)**. These closed loop systems monitor resin feed, substrate feed and conditioning, temperatures, pressures, screw speed, line speed, coating gauge, output, etc., and make adjustments when values drift outside preset limits. VDT monitors display operating conditions, and management information systems software provide hard-copy reports, such as shift reports, monthly reports and/or job summaries. A microcomputer also can be set up to run a coating operation using values from a previous run, stored in the memory. The microcomputer also is a key element of statistical process control (SPC) and statistical quality control (SQC) programs. Real-time SPC systems alert operators when the extrusion coating process is drifting out of its control limits and indicate potential sources of problems.

## Start-Up of An Extrusion Coating Line

### Safety First

Extrusion coating can become a hazardous operation if proper safety precautions are not followed.

- The extrusion equipment should be kept clean and well maintained at all times.
- Remove any water around the extrusion coating line to prevent slipping accidents.
- Good housekeeping is essential.
- Loose pellets on and around the extruder can cause accidents.
- “NO SMOKING” signs must be enforced.
- Allow only trained and qualified personnel in the operating areas.
- Make sure all high voltage areas are identified and suitably grounded.
- Keep areas around the extrusion coating line clear of boxes, barrels and other impediments.
- Obtain and read the MSDS for all materials used in the extrusion coating process.
- Wear proper protection (clothing, eyewear, safety shoes, etc.) as required by the NSDS or equipment manufacturer.
- Make sure proper ventilation systems are installed and operating when solvents are used; corona or another treatment method is operating; or another procedure is underway which requires such systems.

### Heat

High temperatures are used in extrusion coating. Always use heat protective gloves, safety glasses and protective clothing. Signs on the extruders should indicate specific hot areas on the machines. Since flame treatment is used on many lines, fire and personal protection is required.

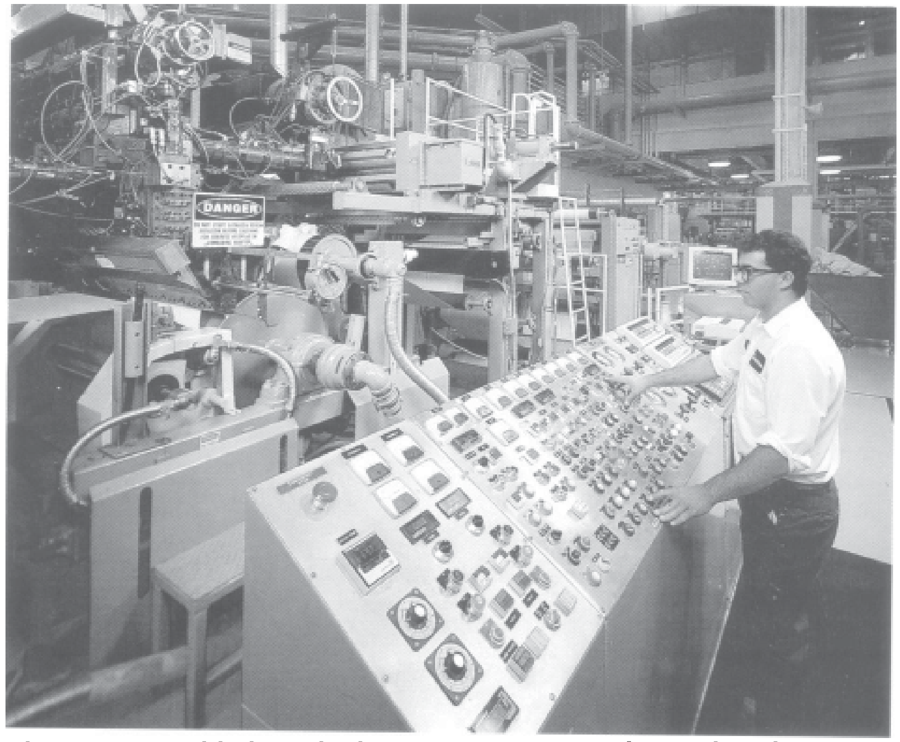


**Figure 53. Sophisticated microprocessor controls monitor the extrusion coating line at LyondellBasell's Cincinnati Technology Center.**

### Electricity

Signs on the extruders should also warn about electric shock hazard areas on the machines. Keep water away from these areas. Periodically check all electrical devices and connections.

### Ventilation

Adequate ventilation is a must when working with hot resins. High temperatures in the die may result in decomposition products. Carefully follow the recommended handling and processing conditions provided by materials suppliers.

### Machinery Motion

Considerable mechanical movement occurs during the extrusion coating operation. Avoid wearing ties and other loose-fitting clothing since loose items can get caught by the moving equipment. Make sure all people working near the extrusion line know where the **EMERGENCY SHUT-OFF BUTTON** is located. **NEVER** disengage any of the safety mechanisms on the extrusion line. **DO NOT OPERATE** equipment with protective guards removed. Install warning signs where necessary.

### Heavy Components

Many of the components of an extrusion coating line are extremely heavy. Use appropriate lifting equipment when changing and/or adjusting these components. Safety shoes (ANSI 2-87) are required.

Prior to start-up, check to see that all safety devices are in place and operational. Walk around the machine to be certain that there are no obstructions to the machine’s movement and that no one is working too close to the line. The extruder should be backed away from the pressure and chill roll unit.

Be sure to have the following available before start-up:

- Safety glasses for everyone assisting in the start-up (at least two operators are needed).
- Loose fitting, heavy-duty work gloves
- A large metal container (drool pan) for collecting melt produced during the start-up and shut-down procedures.
- Soft metal tools for use in removing plastic from the die area and for cleaning the die lips and die gap.

- A sharp safety cutting knife for use in cutting the web on the windup rolls and for preparing the new substrate rolls for extrusion coating. The knife must retract when not in use.

### Guidelines For Start-Up

A wide range of extruders can be used with polyolefins. Therefore, the following procedures for start-up and shut-down are provided only as a general guide. The operating manual for the specific extruder should be closely followed.

1. Turn on the cooling systems for the hopper and the screw,
2. Turn on all the heaters in stages. **(Table 10)**
3. Put drool pan under die.
4. When the die temperatures have reached at least 500°F (260°C), start the screw drive motor at the minimum speed. Gradually raise the speed to 18 to 20 rpm.
5. If the screw does not rotate, the barrel heaters have not been on long enough. Turn off the extruder drive and wait 10 to 15 minutes for the heaters to bring the polymer to a molten state.
6. As the screw rotates, watch the screw load: if it exceeds 100% or the maximum amperage, reduce the screw RPM (i.e., speed).
7. Now purge and clean the die. Use a drool pan until the melt coming out the die appears to be clean and consistent. Now the extruder is ready for the coating operation.
8. Adjust the back pressure valve to increase the work being done on the resin to reach the desired melt temperature. [NOTE: Never set any heater above the desired melt temperature.]
9. Adjust the deckling to roughly obtain the desired coating width.
10. Run the screw speed back to the minimum. Stop the extruder long enough to carry out the next six steps, which should not take longer than three minutes.
11. Remove the drool pan.
12. Move the extruder into the final coating position, i.e., just above the nip of the pressure and chill rolls (the nip should be in the open position).
13. With the substrate in the line from the unwind to windup, start the line drive in tread speed.

**Table 10: Temperature Profile for LDPE Extrusion Coating**

| | Initially | After 1 Hour | After 1½ Hour |
|---|---|---|---|
| Barrell Zone #1 | 300°F | 350°F | 350°F |
| Barrell Zone #2 | 450°F | 525°F | 550°F |
| Barrell Zone #3 | 500°F | 575°F | 600°F |
| Barrell Zone #4 | 500°F | 575°F | 610°F |
| Barrell Zone #5 | 500°F | 575°F | 610°F |
| Adapter | 500°F | 57\5°F | 610°F |
| All Die Zones | 500°F | 575°F | 610°F |

Check with your resin supplier for specific recommendations for other polymers

**Table 11. Operating Recommenations for Various Substrates**

| Main Objectives | Substrates | | | |
|---|---|---|---|---|
| | Paper & Cloth | Paperboard | Metal Foil | BOPP Film |
| Adhesion | X | X | X | X |
| Clarity | X | X | X | X |
| Heat Sealing | X | X | X | X |
| **Operating Conditions Recommended** | | | | |
| Let melt fall against the pressure roll slightly above the nip | X | X | X | X |
| Minimum melt temp-erature compatible with good adhesion | X | X | X | X |
| Cool Chill Roll — 60°F to 80°F (21°C to 27°C) | X | X | X | X |

14. Close the nip.
15. Start the extruder screw again and bring the screw and the line up to the running speeds.
16. Check operating temperatures. They should be at the desired levels. Adjust the back pressure valve to achieve the desired melt temperature.
17. Adjust the windup tension so that the take-off is firm and at the correct tension for the substrate.
18. Set the edge trimmers to the desired width. Bring the slitters in contact with the coated substrate.
19. Feed the edge trim into the trim disposal system.
20. Raise the line speed to the desired level.
21. Make all quality checks after the line and extruder have settled out, and complete final adjustments.

## Shut-Down Guidelines for Extrusion Coating Lines

For shut-down, follow these steps:

1. Decrease the line speed to 50 fpm (15 mpm) or less and decrease the screw speed to the minimum.
2. Turn off the screw.
3. Move the extruder back from the nip area**.**
4. Stop the line drive.
5. Put drool pan under the die.
6. Restart the screw and drool the extruder.
7. Purge the extruder with purge compound only if needed. Do not let the screw run “dry.” Shut down the extruder only with clear polyethylene or purge compound.
8. Clean the die lands and seal die lips with a Pogo stick or other mechanism, and stop the extruder. Make sure the die opening is sealed to prevent oxidation.

## Optimizing the Extrusion Coating Process

After starting up an extrusion coating line, various steps can be taken to optimize its operation.

### Line Speed

One method of reducing the cost of extrusion coating is by increasing coating speeds. The surface speed of the chill roll is, of course, limited by the drawdown properties of the melt coating. Too high a speed may cause tear-offs and voids (holes) in the coating. These problems can best be prevented by using polyolefin resins with unusually high uniformity and excellent drawdown strength.

High coating speeds are not always required or even desirable. Line speed, i.e., chill roll speed along with extruder screw speed, controls coating thickness (coating weight). Coating weight depends on the requirements of the finished product. Line speeds range widely from 50 to 3,000 feet (15 to 915 m) per minute. The slowest speeds are used to lay on heavier coatings or, occasionally, where maximum adhesion is a prime requirement. In higher volume, thin-coating work, the extrusion coater may be run at high line speeds up to 3,000 ft./min. (915 m/min.).

### Adhesion

A coating which can easily be peeled off is worthless. Good adhesion is, therefore, the most important consideration in extrusion coating. A better bond between substrate and coating also means better heat seal strength. Good adhesion of the coating to the substrate depends upon a number of factors, including the type of substrate, type of priming, resin flow, stock temperature, coating speed and coating weight **(see Table 11)**.

Porous substrates, such as paper or cloth, have a natural tendency to hold onto a coating because of the penetration of the hot melt into the substrate. This kind of adhesion is called a physical or mechanical bond.

Most smooth, non-porous substrates, such as metal foils, plastic films or even glassine, have no physical means of clinging to a coating. They tend to resist adhesion, and the substrate and coating must be chemically bonded. To obtain a chemical bond, a trace of oxidation on the polymer surface is necessary. Such oxidation requires:

- A high melt temperature
- An adequate drawdown distance or “air gap” between the point where the hot melt leaves the die and the point where it solidifies, that is, the chill roll/pressure roll nip.

An adequate air gap, although it cools the web (which impairs adhesion), is needed simply to give oxidation time to occur. When coating porous substrates, oxidation plays a role also, although to a lesser degree. The recommended gap between die and nip is seven to nine inches (18 to 23 cm). It may be less for some porous substrates or where very good adhesion is not desirable. The air gap can be adjusted by raising or lowering the extruder or the chill roll assembly.

The hot film can be treated with ozone just before it is pressed against the substrate to help increase bond strength and line speeds and reduce extrusion temperatures. However, ozone is corrosive and toxic in concentrated amounts. The treater station should be made of materials that withstand ozone attack, such as stainless steel or aluminum and adequate ventilation is essential.

Preheating the substrate before it reaches the pressure roll promotes adhesion of the coating to some porous materials, such as kraft paper, paperboard or cloth. Preheating makes the surface more receptive to the molten film. Preheating also helps remove moisture. However, preheating cannot dry a really wet, porous web. Adhesion to a wet substrate is always poor. A wet substrate should be oven-dried before it is fed into the coater. To preheat, pass the substrate over a steel drum that is internally heated by steam or electricity to about 350°F to 375°F (176°C to 190°C).

Resin flow properties affect the adhesion of polyolefin resins to porous substrates since the ability of a resin to penetrate the substrate’s surface depends on the viscosity of the molten web, as well as the porosity of the substrate. Higher melt index resins, with their lower viscosities, adhere better to porous substrates than do lower melt index resins.

Any factor that reduces the amount of oxidation of the hot polyolefin web reduces its adhesion to the substrate. Low coating speed and high coating weights tend to promote adhesion because more time is available for oxidation to occur. As thinner coatings are extruded, they cool more between the die lip and the roll nip. Hence, adhesion may be poorer. The lower the coating weight, the higher the air gap required to obtain good adhesion. Conversely, the higher the coating weight, the lower the required air gap. Too low a chill roll temperature also impairs adhesion.

A high, well controlled, resin temperature in the die and at the point where the resin first contacts the substrate are essential for good adhesion. High melt temperatures (600°F [315°C] or higher) are required to chemically bond a polyolefin coating to paper, for example.

Although high melt temperature is a critical factor in extrusion coating, high temperatures can adversely affect the coated substrate's sealability. High temperatures in the die may also result in odor and smoke during production. Negative pressure ventilation systems are essential **(see Table 12)**.

**Table 12: Main Factors Affecting the Bond Between Resins and Substrates**

- **Substrate Type and Surface**
- **Coating (Melt Temperature)**
- **Air Gap**
- **Resin Flow Properties (Melt Index)**
- **Coating Speed**
- **Coating Thickness**
- **Preheating of Substrate**
- **Nip Pressure**
- **Primer**
- **Corona or Flame Pretreating of the Substrate**
- **Ozone Treating of the Extrudate**

### Voids, Holes and Tears

Voids in the extrusion coating are generally caused by volatile components in the polymer melt or the substrate. Too high a temperature anywhere in the extruder may break down the polyolefin into volatile, vaporizing agents that cause bubbling and result in voids. Rapid changes in temperature, humidity or both, between the storeroom and extrusion shop may cause moisture to condense on the resin pellets. When the moisture is present in such quantities that it cannot be vented back out the hopper, it evaporates and may cause voids. Substrates may also absorb moisture before coating, which leads to voids. Voids may occur when oxidized resin particles collect in the die.

Pinholes can result if fibers from the substrate penetrate very thin extrusion coatings. Flame treating can prevent pinholes. Holes, edge tears, breaks and other defects can also indicate that operating conditions need to be changed. One of the following solutions or a combination may prevent these defects:

- Keep the resin dry and tree from foreign matter.
- Keep the barrel, screw, screen pack and die clean. Do not let this equipment become soiled with degraded resin or foreign matter.
- Adjust the die properly to keep the gauge uniform and eliminate thin areas.
- Prevent surging. Keep the temperature along the die uniform.
- Keep the resin feed throat cool (around 80°F [27°C]).
- Use only virgin resins that are free of fines, and prevent contamination from entering resin feed system. When changing resins, the extruder and die must be purged with the incoming resin long enough to assure that no previously used polymer is in the die (15 to 30 minutes).

### Neck-In

When the hot film is drawn down onto the cool chill roll, it exhibits "neck-in," or shrink at the edges **(see Figure 35, page 23)** Neck-in is the difference between the hot melt width at the die face and the coating width on the substrate. The smaller the drawdown distance between die and chill roll (air gap) and the narrower the die opening is set, the less neck-in. However, for good adhesion of the melt web to the substrate, the air gap must have a certain minimum length, so some neck-in must be expected. Increased neck-in can be caused by:

- Deckling —-but there is no way to eliminate neck-in due to deckling since it is not practical to have a separate die for each substrate width.
- Too high a melt temperature.
- Too great a die speed: decrease the die setting and decrease neck-in.
- Too slow a coating speed: increase coating speed and decrease neck-in slightly.
- A resin with too high a melt index or density: decrease melt index, density or both and decrease neck-in. An optimum combination of these two properties must eventually be determined for successful coating.

Wherever there is neck-in, "beading" also takes place **(see Figure 35, page 23)**. Beading is a thickening of both edges of the coating film. If the beaded edges are not trimmed, then the final roll of coated substrate sags in the middle because of the thickness of the ends. The sagging can result in breaking edges, wrinkling and difficulties in converting the roll later. Special internal deckling can be used to virtually eliminate beading **(Figure 36, page 23)** and loss of resin.

### Coating Thickness (Gauge)

Variances in the thickness (gauge) of the coating generally are due to problems in the die. If the die and die lips are not clean, thin bands can occur in the coating. Problems with die heaters can also cause temperature striations that result in gauge bands.

Uneven extrusion (non-uniform flow) from the die is called surging. Surging may result in non-uniform coating gauge, "applesauce" defects and voids in the coating. **Table 13** provides some possible reasons for surging.

## Process Variables Affecting Properties of Extrusion Coatings

Various steps can be taken to optimize the performance of extrusion coated substrates.

### Barrier Properties

Thickness uniformity is the most important processing factor affecting barrier properties. With very thin coatings, blemishes and imperfections (pinholes, fisheyes, etc.) reduce barrier properties. Furthermore, some

**Table 13: Reasons for Surging and Their Causes**

| Problem | Possible Causes of Surging |
| --- | --- |
| Variations in Melt Temperature | The screw is too hot in the feed section so that the resin sticks together at the feed throat, causing bridging. |
| Variations in Resin | A poorly designed screw. |
| | A barrel heater is burned out or faulty, causing variationsn in electric heating (or an instru-ment is faulty) |
| | The resin is improperly mixed because the barrel is too short. |
| | Bridging when the screw fee is too hot. |
| | The motor belt is slipping. |
| | Die surfaces obstruct smooth melt flow. |
| | The screw fabrication could be at fault. |

additives and colorants also can reduce a coating's barrier properties. Resin density also determines barrier properties.

## Clarity

The main factor affecting clarity is the choice of resin. However, the clarity of an extrusion coating improves with increasing processing temperatures and faster cooling. Clarity is also affected by the chill roll used. A high gloss or mirror pocket chill roll yields a higher clarity coating. A matte-finish chill roll results in a coating with low clarity.

## ESCR

Varying processing variables has little or no effect on ESCR. Resin choice is the most important factor. LLDPE resins have excellent ESCR.

## Gauge Uniformity

The problem of poor gauge uniformity in extrusion coating is quite common. Variations in gauge of less than ±10% are not considered a problem. Variations exceeding this level require corrective steps. Non-uniform melt temperature may result in non-uniform extrusion coating gauge and other defects.

Hot polymer forms a flow channel that can cause gauge bands. When the gauge bands are adjusted, a new gauge band is created on either side of the original one, since the hot melt flow must go somewhere. The source of the hot melt flow must be identified and corrected before uniform coating thickness can be attained

Overheated melt may come out of the die too fluid, resulting in a coating that is difficult to cool and peel off the chill roll. Poor mixing may also result in non-uniform extrusion coating thickness. It is essential to periodically measure gauge on a cut piece of coated substrate or with a built-in electronic gauge-measuring and recording device.

## Gloss

Extrusion coating gloss improves with increasing operating temperatures. Gloss is also affected by the chill roll that is used. A high gloss or mirror pocket chill roll yields a glossier coating. A matte-finish chill roll reduces the gloss of the coating.

## Heat Sealability

Various factors can adversely affect heat sealability. If the air gap is too great, melt temperatures too high or corona treatment excessive, oxidation occurs and affects the coating's heat sealability. Additives (antistats, slip agents, dispersion agents) also reduce the coating's heat sealability.

## Slip

Polyolefin coated substrates to be made into bags or pouches must not block, i.e., coated sides must not stick to each other. Slip prevents blocking from occurring. Slip is affected by such processing factors as coating temperature, chill roll temperature and surface and treatment, A high coating temperature and a highly polished chill roll, while having beneficial effects on adhesion and coating gloss, definitely contribute to blocking. A matte chill roll improves slip properties considerably. Increased chill roll temperature increases slip and decreases blocking to a degree. If a substrate is to have a glossy coating, a polyolefin resin containing a slip additive should be used. These additives however, can result in some loss of adhesion.

## Stiffness

The main factor affecting stiffness is the resin choice (higher density resins yield stiffer films). Process conditions in the barrel and screw can affect the stiffness or "feel" of the film.

## Strength

The most important factor controlling strength (including tear, puncture and tensile) is the choice of resin. Naturally however, blemishes and imperfections (pinholes, fisheyes, etc.) reduce strength properties.

## Toughness

The main factor affecting toughness is the resin choice. Extrusion coating toughness generally is best with the more difficult to process resins, i.e., the low MI, high molecular weight grades.

## Appendix 1:
## Common Coating Problems and Their Causes

| Coating Problems | Possible Causes |
|---|---|
| **Poor Clarity** | Extrusion temperature too low<br>Inadequate cooling<br>Rough finish on the chill roll<br>Unsuitable resin |
| **Wrinkles on the Windup Roll** | Gauge variations caused by die or cooling defects<br>Insufficient or unequal cooling<br>Inadequate tension control at the rewind<br>Idler rollers not in train |
| **Coating-Film Structure Defects such as Applesauce** | Extrusion temperature too low or high<br>Poor mixing<br>Poor screw design |
| **Coating-Film Defects such as Gels and Fisheyes** | Poor mixing<br>Flaking away of oxidized polymer caused by a dirty screw and/or barrel<br>Insufficient purging after changing resins<br>Contaminated resin due to lack of cleanliness in the shop, mixing the resin with scrap or reground polymer<br>Faulty start-up or shut-down<br>Resin hang-up<br>Hot hopper inlet section<br>Poor resin quality |
| **Streaks in Coating** | Inadequate mixing<br>Foreign matter held up in die<br>Impurities in the die lands<br>Scratches in the die lands<br>Burrs in the idler rolls<br>Idler rolls not turning |
| **Wide Coating Thickness Variations** | Non-uniform temperature at the die opening<br>Non-uniform cooling across the melt<br>Non-uniform flow at the die opening (probably caused by surging)<br>Non-uniform die gap opening |
| **Poor Winding** | Non-uniform gauge<br>Poor rewind tension control<br>Excess slip additive in the resin<br>Inadequate rewind equipment<br>Too much blocking<br>Inadequate cooling of the coated substrate before windup<br>Chill roll too highly polished<br>Overtreatment<br>Improper  wind-up tension<br>Improper idler roll alignment |
| **Adhesion,  Ppoor or Spotty Bonds** | Low melt temperature<br>Improper air gap<br>Heater malfunction<br>Substrate surface not prepared; corona treatment or primer required<br>Chill roll temperature too high or low<br>Use of silicone sprays<br>Incorrect nip roll impression |

## Appendix 1: (Continued)
## Common Coating Problems and Their Causes

| Coating Problem | Possible Causes |
|---|---|
| **Coating Film Defects** | |
| **Applesauce** | Extrusion temperature too high or low<br>Poor mixing<br>Resin contamination; improper purging technique |
| **Gels** | Insufficient purging after resin change<br>Contaminated resin: transfer lines not cleaned or storage boxes not covered<br>Over-oxidized polymer as a result of high melt temperatures<br>Overheated hopper feed section; water cooling passages clogged |
| **Edge Tear** | Improper die design<br>Die temperature ends too low<br>Deckle settings too wide or narrow<br>Deckle seal strip improperly set up |
| **Gauge Bands** | Heater malfunction; melt temperature variation<br>Dirty die<br>Die gap opening not uniform<br>Melt temperature too high<br>Improper melt back pressure control |
| **Pinholes** | Rough substrate<br>Low polymer coating<br>Gels<br>High tension settings on line drives<br>Dirty or damaged idler rollers |
| **Voids** | Wet polymer; moisture pickup due to quick temperature changes or resin handling<br>Gels<br>Melt temperature too high<br>Dirty die |
| **Surging** | Hot hopper inlet section from poor water circulation<br>Improper screw design<br>Improper process conditions |
| **Draw Resonance** | Improper air gap<br>Melt temperature too high<br>Wrong resin used for job<br>Improper die gap |
| **Oxidation** | Improper air gap<br>Melt temperature too high<br>Improper purging technique; possible resin contamination<br>Shut-down procedure problems: screw turned off too soon<br>High treater settings on barrel down stream zones |
| **Curtain Tear-Outs or Breaks** | Improper die gap<br>Melt temperature too low<br>Low back pressure<br>Low coating thickness<br>Improper deckle set-up |
| **Heat Sealability Problem** | Over-oxidation: high melt temperature or improper air gap setting<br>Excessive corona treatment<br>Additives or excessive use of silicone sprays, resulting in surface contamination |

## Appendix 2:
## Formulas for the Extrusion of Polymers

**1. Output, lbs/hr**

$$\frac{\text{(FPM) Width, in.) (basic weight)}}{600}$$

**FPM = line speed**
**basic weight = gauge desired**
**Width = die opening**

**2. Output, lbs/RPM**

$$\frac{\text{lbs./hr}}{\text{RPM}}$$

**3. Horsepower**

$$\frac{\text{(volt) (amp)}}{750}$$

**4. Outputs, lbs/hp**

$$\frac{\text{lbs/hr}}{\text{HP}}$$

**5. RPM**

$$\frac{\text{lbs/hr}}{\text{lbs.RPM}}$$

## Appendix 3: Cleaning the Extruder and Its Parts

A definite periodic cleaning schedule should be established for the extrusion coating line. The time interval between thorough cleaning can best be determined by experience. Standard operating procedures should be developed for specific machines operated under specific conditions in the shop. The following are general guidelines only.

**How to Clean the Extruder**

Over long periods of operation, a layer of oxidized polymer slowly builds up on the inside barrel walls, the screw and the die. Eventually, this degraded resin will begin to flake off. This in turn results in coating defects, such as gels or yellow-brown oxidized particles. Such defects cause the coating to have a poor appearance, especially in very thin coatings.

The following disassembly steps are suggested prior to cleaning the extruder:

1. Refer to the MSDS on the materials run most recently to learn about potential hazards if decomposition occurs.
2. Let the extruder run with resin, without further feeding, until the screw can be seen when the hopper is uncovered. Do not let the screw run “dry”.
3. Turn off all electricity and water cooling.
4. Move the extruder away from the windup equipment and remove anything else in line with the screw while the machine is still hot. Wear protective gloves. Make sure that the hazards of volatile and other resin decomposition products are eliminated.
5. Disconnect electrical and water lines.
6. Remove the die. Use heavy-duty carrying equipment, an overhead crane or fork lift truck.
7. Remove the barrel cover and the adapter from the barrel.
8. Remove the breaker plate and screens from the adapter.
9. Push the screw forward with a rod from the back end of the barrel and remove it. Now, you have access to all the extruder parts to be cleaned orexchanged.

To clean the screw, first use a copper or brass knife (putty knife) to remove most of the molten resin adhering to the screw. Do not use a steel blade. Next, clean the screw with copper or brass wool. Use a silicone grease and/or nonchlorinated scouring powder to remove stubborn resin. But use the silicone grease sparingly; residual silicone can cause problems in extrusion coating for days. Finally, coat the screw with a thin layer of castor oil.

To clean the barrel, run a brass brush at the end of a long handle through the barrel to remove any resin build-up. Lubricate the barrel with a thin layer of castor oil. To clean the adapter, also use copper or brass tools. Clean the collar. Clean and lubricate the seat of the adapter. The face of both the adapter and the barrel must be clean in order to make a good seal on reinstallation. To clean the breaker plate, it is necessary to burn away the oxidized polymer with a Bunsen burner. The polymer may be clinging to or possibly clogging the plate. Specially designed cleaning ovens or fluidized baths may also be used for cleaning breaker plates or small parts.

To clean the extrusion coating die, remove the fixed die lips while they are hot. If the die lands are separate from the lips, remove them. Scrape the lands, the manifold and the fixed and adjustable lips free of resin with a brass or wooden “knife.” Use only copper or brass tools for cleaning all the parts. Finish the cleaning with a copper-wool cloth or brush. Polish the curved surfaces of the manifold with a very fine grit polishing cloth, and hone the manifold’s flat surface to remove any mars or scratches. Reassemble all the parts. Set the opening between the die lands to the desired width with a feeler gauge or shim made of brass or some “soft” metal which does not mark the lands. The recommended die gap opening is 0.030 inch (0.008 mm).

To clean the pressure rolls, use a cloth saturated with ethyl or isopropyl alcohol. Make sure to work in a well ventilated area. If there are minor scratches or nicks in the pressure roll, it must be refinished, which can be done with a coarse emery cloth, followed by polishing with a piece of felt. Repairs of more significant damage, such as cracks, surface hardening, gouges, etc., require removal of the roll and regrincling or resurfacing.

To clean the chill roll, also use an ethyl or isopropyl alcohol -saturated cloth. Make sure to work in a well ventilated area. Take special care not to mar the chill roll surface in any way. Check the surface to make sure that it is perfectly flat. Periodically, the chill roll must be reconditioned: a new, flat, highly polished surface applied and the cooling water channels cleaned. Chill roll manutacturers generally offer this service. A replacement chill roll should be available while the current roll is sent out for reconditioning.

## Appendix 4:
## Metric Conversion Guide

| To Convert From | To | Multiply By |
|---|---|---|
| **Area** | | |
| square inches | square meters | 645.16 |
| square millimeters | square inches | 0.0016 |
| square inches | square centimeters | 6.4516 |
| square centimeters | square inches | 0.155 |
| square feet | square meters | 0.0929 |
| square meters | square feet | 10.7639 |
| **Density** | | |
| pounds/cubic inch | grams/cubic centimeter | 7.68 |
| grams/cubic centimeter | pounds/cubic inch | 0.000036 |
| pounds/cubic foot | grams/cubic centimeter | 0.016 |
| grams/cubic centimeter | pounds/cubic foot | 62.43 |
| **Energy** | | |
| foot-pounds | Joules | 1.3558 |
| Joules | foot-pounds | 0.7376 |
| inch-pound | Joules | 0.113 |
| Joules | inch-pounds | 8.85 |
| foot-pounds/inch | Joules/meter | 53.4 |
| Joules/meter | foot-pounds/inch | 0.0187 |
| foot-pounds/inch | Joules/centimeter | 0.534 |
| Joules/centimeter | foot-pounds/inch | 1.87 |
| foot-pounds/square inch | kilo Joules/square meter | 2.103 |
| Joules/square meter | foot-pounds/square inch | 0.4755 |
| **Length** | | |
| mil | millimeter | 0.0254 |
| millimeter | mil | 39.37 |
| inch | millimeter | 25.4 |
| millimeter | inch | 0.0394 |
| **Output** | | |
| pounds/minute | grams/second | 7.56 |
| grams/second | pounds/minute | 0.1323 |
| pounds/hour | kilograms/hour | 0.4536 |
| kilograms/hour | pounds/hour | 2.2046 |
| **Power** | | |
| kilowatts | horsepower(metric) | 1.3596 |
| horsepower (metric) | kilowatts | 0.7376 |
| voltage/mil | millivolts/meter | 0.0394 |
| millivolts/meter | voltage/mil | 25.4 |

# Metric Conversion Guide

| To Convert From | To | Multiply By |
|---|---|---|
| **Pressure** | | |
| pounds/square inch (psi) | kilopascals (kPa) | 6.8948 |
| kilopascals (kPa) | pounds/square inch (psi) | 0.145 |
| pounds/square inch (psi) | bar | 0.0689 |
| bar | pounds/square inch (psi) | 14.51 |
| **Temperature** | | |
| °F | °C | (°F-32)/1.8) |
| °C | °F | 1.8°C+32 |
| inches/inch | F meters/meter,C | 1.8 |
| meters/meter,C | inches/inch,F | 0.556 |
| **Thermal Conductivity** | | |
| Btu-in/hr, sq. ft.,°F | W/(m-°K) | 0.1442 |
| W / (m-°K) | Btu-in/hr,sq ft, °F | 6.933 |
| **Thermal Expansion** | | |
| inches/inch,°F | meters/meter,°C | 1.8 |
| meters/meter, °C | inches/inch, °F | 0.556 |
| **Viscosity** | | |
| poise | Pa-sec. | 0.1 |
| Pa-sec | poise | 10 |
| **Volume** | | |
| cubic inch | cubic centimeter | 16.3871 |
| cubic centimeter | cubic inch | 0.061 |
| cubic foot | cubic meter | 0.0.83 |
| cubic yard | cubic meter | 0.765 |
| **Weight** | | |
| ounce | gram | 28.3495 |
| kilogram | ounce | 0.03527 |
| pound | kilogram | 0.4536 |
| kilogram | pound | 2.2046 |
| ton (US) | ton (metric) | 0.972 |
| ton (metric) | ton (US) | 1.1023 |
| **Coating Weight** | | |
| grams/meter$^2$ | pounds/3,000 ft$^2$ | 0.614 |

## Appendix 5:

## Abbreviations

| | |
|---|---|
| **ACS** | American Chemical Society |
| **APC** | Automated process control |
| **ASTM** | American Society for Testing and Materials |
| **BOPP** | Biaxially oriented polypropyene |
| **Btu** | British thermal unit |
| **DB** | Dinkelberry. Caused by leaking die end plates, deckles or other extruder matting surfaces. |
| **deg** | Degree (angle) |
| **E** | Modulus of elasticity |
| **EAA** | Ethylene acrylic acid copolymer |
| **EEA** | Ethylene-ethyl acrylate copolymer |
| **elong** | Elongation |
| **EMAA** | Ethylene methyl acrylic acid copolymer |
| **EnBA** | Ethylene-n-butyl acrylate |
| **ESCR** | Environmental stress cracking resistance |
| **EVA** | Ethylene vinyl acetate copolymer |
| **EVOH** | Ethylene vinyl alcohol copolymer |
| **FDA** | Food and Drug Administration |
| **flex** | Flexural |
| **FPA** | Flexible Packaging Association |
| **FR** | Flame retarant |
| **g** | Gram |
| **GP** | General purpose |
| **HALS** | Hindered amine light stabilizer |
| **H/C** | Hopper Car |
| **HDPE** | High density polyethylene |
| **HMW** | High molecular weight |
| **imp** | Impact |
| **IR** | Infrared |
| **J** | Joule |
| **K** | Kelvin |
| **kpsi** | 1,000 pounds per square inch |
| **L/D** | Length to diameter ratio of screw |
| **lbf** | Pound-force |
| **LDPE** | Low density polyethylene |
| **LLDPE** | Linear low density polyethylene |
| **MD** | Machine direction |
| **MDPE** | Medium density polyethylene |
| **MI** | Melt index |
| **MIL** | Military, as in Military Standard (MIL STD) |
| **mod** | Modulus |
| **mol%** | Mole percent |
| **MU** | Greek mu |
| **MVTR** | Moisture vapor transmission rate |
| **MW** | Molecular weight |
| **N** | Newton |
| **OPP** | Oriented polypropylene |
| **PA** | Polyamide |
| **PBT** | Polybutylene terephthalate |
| **PE** | Polyethylene |
| **PET** | Polyethylene terephthalate |
| **PP** | Polypropylene |

## Appendix 5: (Continued)

### Abbreviations

| | |
|---|---|
| **pphr** | Parts per hundred resin, parts per hour |
| **ppm** | Parts per million |
| **psi** | Pounds per square inch |
| **PVdc** | Polyvinylidene |
| **RH** | Relative humidity |
| **rpm** | Revolutions per minute |
| **SCR** | Silicon controlled rectifier |
| **sp gr** | Specific gravity |
| **SPC** | Statistial process control |
| **SPE** | Society of Plastics Engineers |
| **SPI** | The Society of the Plastics Industry |
| **SQC** | Statistia quality control |
| **TAPPI** | Technical Association of the Pulp and Paper Industry |
| **TD** | Transdirectional |
| **ten** | Tensile |
| **Tg** | Glass transition temperature (crystalline polymers) |
| **T/L** | Truckload |
| **Tm** | Melt temperature (amorphous polymers) |
| **TPO** | Thermoplastic olefin |
| **UHMW-HDPE** | Ulta-high molecular weight HDPE |
| **ult** | Ultimate |
| **UV** | Ultraviolet |
| **VAM** | Vinyl acetate monomer |
| **WVTR** | Water vapor transmission rate |
| **yld** | Yield |

# Appendix 6:

## GLOSSARY

**Air Gap:** The vertical distance between the die lips and the nip to chill roll contact point.
**Applesauce:** Rough wavy appearance on the surface of the polymer curtain, sometimes called Orange Peel. It occurs when the plastic has not been uniformly homogenized.
**Aging:** Change of a material with time under defined environmental conditions, leading to improvement or deterioration of properties.
**Air Jet:** Device used to cool and stabilize the polymer edge.
**Alloy:** Composite material made by blending polymers or copolymers with other polymers or elastomers under selected conditions, e.g., polypropylene-rubber blends.
**Amorphous Phase:** Devoid of crystallinity; no definite order. At processing temperatures a plastic is normally amorphous.
**Angle of Repose:** Minimum angle for the hopper wall design. It is equivalent to the angle formed when the resin is placed in a pile on a flat surface.
**Annealing:** Holding a material at an elevated temperature below its melting point to permit stress relaxation without distortion of shape.
**Antiblock:** Additive that prevents an undesired adhesion between touching layers of a material, such as occurs under moderate pressure during storage or use.
**Antioxidant:** Substances that prevent or slow down oxidation of polymers exposed to air.
**Antistatic Agent:** Additives that minimize static electricity in polymers.
**Arrowheads:** Imperfections in film resembling "arrowheads".
**Auto-oxidation:** Self-sustained oxidation of a polyolefin after initial exposure to some oxidizing agent, such as molecular oxygen.
**Average Molecular Weight:** Most synthetic polymers are a mixture of individual chains of many different sizes, hence a molecular weight for such a mixture is an average molecular weight.
**Beta Gauge:** Gauge consisting of two facing elements, a "ß"-ray-emitting source and a "ß-ray detector. When a sheet material (substrate) is passed between the elements, the "ß" -rays absorbed are a measure of the density or thickness of the sheet.
**Beta Scission:** Abstraction of hydrogen from the polymeric backbone, causing chain breakage, resulting in a marked reduction in melt viscosity.
**Bleed:** To give up color when in contact with water or a solvent. Also, the undesired movement of certain materials to the surface of a finished article or onto an adjacent material.
**Blister:** Raised area on the surface of a coated substrate or molded plastic caused by the pressure of gases inside the area's independently hardened surface, sometimes created by entrapped air between a substrate and the coating,
**Blocking:** Undesired adhesion between touching layers of material, which can occur if the materials are under moderate pressure during storage or use.
**Blooming:** Movement of an additive to the surface of the finished article.
**Blowing Agents:** Chemical additives that generate inert gases when heated and cause the polymer to assume a cellular structure.
**Branched:** In the molecular structure of polymers, this refers to side chains attached to the main chain,
**Breaker Plate:** Perforated plate located in an extruder head. It often supports screens that prevent foreign particles from entering the die.
**Bulk Density:** Mass per unit volume of a powdered or pelletized material as determined in a reasonably large volume.
**Burning Rate:** Tendency of polymers to burn under given conditions.
**Chill Roll:** Cored roll, usually temperature controlled by circulating water, which cools the web before winding. In extrusion coating, either a polished or matte-surfaced chill roll may be used, depending on the desired finished coating.
**Clarity:** The transparency of a coating.
**Clearance:** Controlled distance between parts of an object.
**Coat-hanger Die:** Extrusion slot die shaped internally like a coat hanger to improve distribution of the melt across the full width of the die.
**Coating Weight:** Weight of coating per unit area.
**Color Concentrate:** Color pigment compounded with a base resin and then let down at a specific ratio with the polymer being extruded to achieve a correct end concentration.
**Compression** Ratio In an extruder screw, the ratio of the channel volume in the first flight at the hopper to that of the last flight at the end of the screw.
**Conditioning:** Subjecting a material to a stipulated treatment so it responds in a uniform way to subsequent testing or processing. The term is frequently used to refer to the treatment given to specimens before testing.
**Copolymer:** Polymeric system that contains two or more monomeric units. Polymer that has a functional chemical group added for improved properties. Examples are EnBA, tie-layers, EAA adhesive polymers, EVA, EMA, EMAA.
**Creep:** Dimensional change with time of a material under load, following the initial instantaneous elastic deformation.
**Crosslinking:** Formation of primary valence bonds between polymer molecules, resulting in a marked increase in melt viscosity. A method of degradation by which molecules join together resulting in an increased high molecular weight proportion. Many gels are actually highly crosslinked material.
**Crystallinity:** Molecular structure in polymers denoting stereo regularity and compactness of molecular chains. Normally can be attributed to the formulation of solid crystals in the polymer with a definite geometric form.
**Curling:** Condition in which a coated substrate rolls in the machine or transverse direction and sometimes in both directions.
**Deckle Rods:** Small rod or adjustable device inserted or attached at each end of an extrusion coating die, used to control the width of the polymer as it leaves the die lips.
**Delamination:** Separation of dissimilar materials into layers.
**Deliquescent:** Capable of attracting moisture from the air.

## Appendix 6: (Continued)

## GLOSSARY

**Density:** Weight per unit volume of a substrate expressed in grams per cubic centimeter, pounds per cubic foot, etc.
**Die Adapter:** Extrusion die part that connects the die to the barrel adapter.
**Die Gap:** Distance between the die lips, forming the die opening, through which the polymer flows, typically 0.020" to 0.040" (0.508mm to 1.016mm).
**Die Lines:** Vertical marks on the film extrudate caused by damage to the die lips or contamination on the die lips' land areas.
**Dinkelberrys:** Drippings from deckles, mating surfaces on dies and adaptors, etc.
**Dielectric Constani:** Ratio of the capacitance of an assembly of two electrodes separated by a dielectric material to the assembly's capacitance when the electrodes are separated by air.
**Dielectric Strength:** Electric voltage gradient at which an insulating material is broken down, given in volts per mil of thickness.
**Dispersion:** Finely divided particles of a material suspended in another substance.
**Doctor Roll, Doctor Bar, Doctor Blade:** Device regulating the amount of liquid material on the rollers of a spreader or applicator,
**Drawdown Ratio:** Ratio of the thickness of the die opening to the final thickness of the product.
**Drawdown Limit:** The complete and instantaneous breaking or tearing of the molten film curtain across its entire width.
**Draw Resonance:** A different form of extrudate drawdown failure characterized by instability of the molten film edge or loss of thickness uniformity across the width of the film curtain. The thickness changes move from side to side and are not confined to one area of the die.
**Edge Bead:** A buildup of polymer along the edges of the web resulting from neck-in of the molten polymer curtain as it exits the extrusion coating die.
**Edgebead Reduction:** A wire rod or shaped mechanism inserted above the final die lip lands from each end of the extrusion coating die. This device reduces or eliminates edge bead.
**Edge Tear, Edge Weave:** Weaving or partial tearing of the melt curtain along its edges.
**Elasticity:** Property of a material that allows it to recover its original size and shape after deformation.
**Elongation:** Increase in length of a material under stress.
**Embossing:** To create impressions of a specific pattern in plastic film.
**Environmental Stress Cracking:** Susceptibility of a thermoplastic to crack or craze under the influence of chemical treatment and/or mechanical stress.
**Ethylene Vinyl Acetate:** A copolymer of ethylene and vinyl acetate having many of the properties of polyethylene, but exhibiting increased flexibility, elongation and impact resistance.
**Extrudate:** Product or material delivered by an extruder, such as film, pipe, and the web coating of paper or films, etc.
**Extrusion:** Forcing a heated plastic through a shaping orifice to produce a continuous flow.
**Extrusion Coating:** Coating of a substrate by extruding a thin film of molten polymer and pressing it onto the substrate.
**Film:** Sheeting with a thickness less than 0.010 inch.
**Fisheye:** Fault in transparent or translucent polymer film or sheet, which appears as a small globular mass. Caused by contamination or incomplete blending.
**Flame Treating:** Treating inert thermoplastic materials so they are receptive to inks, lacquers, adhesives, etc. The material is heated in an open flame to promote oxidation on the surface. Paperboard is usually flame treated to promote adhesion of the molten polymer curtain to its surface.
**Flammability:** Measure of the extent to which a material supports combustion.
**Flow:** Fluidity of a plastic.
**Gauge:** Thickness of a single layer of film expressed in mils (0.001 inch = 1 mil).
**Gels:** A film defect characterized by round or oblong clear spots, so hard they can be felt.
**Gel Flurry:** Sporadic appearance of gels in a large area of a film extrudate.
**Gel Streaks:** Groups of gels aligned in the direction of flow in film.
**Glass Transition:** Change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from a viscous or rubbery condition to a hard and relatively brittle one.
**Gloss:** Measure of the ability of a material to reflect incident light. It is a function only of the surface of the material.
**Hardness:** Resistance of a plastic to compression and indentation. Among the most important methods of testing this property are Brinell Hardness, Rockwell Hardness and Shore Hardness.
**Haze:** Degree of cloudiness in a polymer
**Heat Sealing:** Joining plastic surfaces by simultaneous application of heat and pressure to areas in contact. Heat may be supplied conductively or inductively.
**Homopolymer:** Polymer consisting of only monomeric species.
**Hopper:** Conical feed reservoir into which polymer is loaded and from which it falls into the extruder.
**Hot Gas Welding:** Joining thermoplastics by softening the materials with a jet of hot air and pressing together the softened points. A thin rod of the same material is used to fill the gap in some applications.
**Hydroscopic:** Tendency to absorb moisture.
**Impact Strength:** Ability of a material to withstand shock loading.
**Land:** Bearing surface along the top of the flights of a screw in an extruder or the surface of an extrusion die parallel to the direction of melt flow.
**Light Resistance:** Ability of a plastic to resist fading after exposure to sunlight or ultraviolet light,
**L/D Ratio:** Ratio of the extruder length to its barrel diameter.
**Masterbatch:** Plastic compound that includes a high concentration of an additive or additives, i.e.; color pigments, slip, antiblock, etc.
**Melt Flow Rate:** Amount, in grams, of a thermoplastic forced through the orifice of an extrusion plastometer under conditions described in ASTM D 123-F9 (condition L) at 230°C. Normally used for polypropylene.

## Appendix 6: (Continued)

## GLOSSARY

**Melt Fracture:** Instability in the melt flow through a die starting at the entry to the die. It leads to surface irregularities of the finished product.
**Melt Index:** Amount, in grams, of a thermoplastic which can be forced through the orifice of an extrusion plastometer under conditions described in ASTM D1238-F9 (condition E) at 190°C. Normally used for polyethylene.
**Melt Strength:** Strength of a polymer while in a molten state.
**Moisture Vapor Transmission Rate:** Rate at which water vapor permeates through a plastic film at a specified temperature and relative humidity.
**Molecular Weight Distribution:** Measure of the frequency of occurrence of the different molecular weight chains in a homologous polymeric system. The ratio of the weight average molecular weight to the number average molecular weight is sometimes used as an indication of the breadth of the distribution.
**Monomer:** Molecule that can react to form a polymer.
**Neck-In:** Contraction of the molten polymer curtain as it leaves the die. The difference between the die opening width and the finished coating width before trimming off the edge bead.
**Nips:** Rolls in various locations along the length of the coating line including the nips in the coating stations (priming, extrusion) etc,
**Orange Peel:** Surface defect in film resembling the skin of an orange.
**Orientation:** Aligning the crystalline structure of polymers to produce a highly uniform structure accomplished by cold drawing or stretching during fabrication.
**Permeability:** Rate of diffusion of a vapor, liquid, or solid through a barrier.
**Pigment:** Solid, insoluble additive providing opacity or color.
**Poise:** Unit of viscosity.
**Polytillends:** Mechanical mixture of two or more polymers, for example polypropylene and rubber.
**Polyethylene:** Thermoplastic composed mainly of ethylene.
**Polymer:** High molecular weight organic compound, natural or synthetic, with a structure represented by repeating small units.
**Polypropylene:** Tough, lightweight, rigid plastic made by the polymerization of propylene gas in the presence of an organometallic catalyst at relatively low pressures and temperatures.
**Purging:** Cleaning one color or type of material from the barrel of an extruder by forcing it out with a new material or a purge compound, if needed.
**Quench:** The shock cooling of thermoplastics from the molten state.
**Recycle:** Ground material from edge trimmings or drool which, after mixing with certain amount of virgin material, is reused in some extrusion operations (blow molding, injection molding, film and sheet extrusion).
**Rheology:** Study of the flow of polymers on a macroscopic and microscopic level.
**Rockwell Hardness:** A test for plastics measuring resistance to indentation by using a diamond or steel ball under pressure to deform the test specimen.
**Rubber Roll Marks:** A repeat impression made on the coated surface when contamination particles are stuck on a nip roll (rubber roll). After each revolution, the contaminant leaves a mark on the substrate.
**Shear Rate:** Overall velocity of the cross section of a channel at which molten polymer layers are gliding along each other or along a channel in a laminar flow.
**Shear Strength:** Ability of material to withstand shear stress or the stress at which a material fails to shear.
**Shear Stress:** Stress development in a polymer melt when the layers in a cross section are gliding along each other or along a wall of the channel in a laminar flow.
**Sheet:** Flat section of a thermoplastic at least 10 mils thick, with its length considerably greater than its width.
**Shrinkage:** Contraction of a molten material upon cooling.
**Slip Additive:** Modifier that acts as internal lubricant which blooms to the surface of the plastic during and immediately after processing. The additive coats the surface and reduces the coefficient of friction.
**Specific Heat:** Amount of heat required to raise a unit mass by one degree of temperature under specified conditions.
**Stabilizer:** Ingredient used in the formulation of some polymers to assist in maintaining the physical and chemical properties of the compounded materials, for example, heat and UV stabilizers.
**Surface Treatment:** Treating a polymer to render the surface receptive to inks, lacquers, and adhesives. Also used to render the surface of paper, paperboard and film substrates receptive to polymer adhesion. Also refers to processes such as chemical, flame and electronic treating.
**Surging:** Unstable pressure build-up in an extruder leading to variable throughput and waviness of the extrudate.
**Synergism:** Use of stabilizers or slip additives in a polymer when the combination of two or more stabilizers improves the stability of a polymer to a greater extent than would be expected from the additive effect of each stabilizer alone.
**T-Die:** Center-fed, slot extrusion die, which in combination with the die adapter (down-spout), resembles an inverted “T.”
**Tear Strength:** Ability to resist tearing.
**Temperature Profile:** Temperatures along the extruder, adapter, down-spout and die. Usually described by zones starting at the feed zone and progressing to the die lips,
**Tensile Strength:** Pulling stress in pounds per square inch required to deform a given specimen. The original area of the coating is usually used in computing strength, rather than the necked-in area.
**Thermal Stability:** Ability of a polymer to maintain its initial physical and chemical properties at elevated temperatures.
**Treating:** Preparing a substrate for adhesion of a polymer. Preparing a polymer surface to retain inks, adhesives, etc.
**UV Absorbers:** Any chemical compound which, when mixed with a thermoplastic, selectively absorbs ultraviolet rays and retards polymer degradation.

## Appendix 6: (Continued)

## GLOSSARY

**Ventilation:** Blower devices used to remove smoke and fumes from around extrusion coating lines and the extruder die.

**Viscosity:** Internal friction or resistance to flow of a liquid. The ratio of shearing stress to rate of shear.

**Viscosity of Common Liquids in Poise at 25°C**

| | |
|---|---|
| Water | 0.01 |
| Kerosene | 0.10 |
| Motor Oil SAE 10 | 1.0 |
| Castor Oil | 10.00 |
| Glycerin | 10.00 |
| Corn Syrup | 100.0 |
| Molasses | 1000.0 |
| Polymers (typical) | 10,000 to 100,000 (at 200°C) |

**Void:** Bubble or hole in film, caused by gels, hang-up in die lips and moisture in resin.

## Appendix 7:

## TEST METHODS APPLICABLE TO POLYOLEFIN EXTRUSION COATING RESINS AND THEIR SUBSTRATES

| Property | ASTM Method | TAPPPI Method |
|---|---|---|
| **Abrasion Resistance** | | |
| of Paperand Paperboard | | T476 |
| of Plastic Materials | D 1242 | |
| **Adhesion of Polyethylene** | | |
| to Porous Substrates | | T539 |
| to Nonporous Substrates | | T540 |
| **Air Permeability** | | |
| of Paper and Paperboard | | T547 |
| **Blocking Resistance** | | |
| of Paper and Paperboard | D 918 | |
| **Brittleness, Low Temperature** | | |
| of Plastic Film | D 746 | |
| **Burst Strength** | | |
| of Paperboard and Linerboard | D 774 | T807 |
| of Paper | D 774 | T403 |
| **Chemical Resistance** | | |
| of Adhesive Bonds | D 896 | |
| of Plastic Film | D 1239 | |
| **Coefficient of Friction** | | |
| of Packaging Paper | | T542 |
| Density of Plastic Film | D 1505 or D 792 | |
| **Dielectric Constant of Plastic Film** | D 150 | |
| Dissipation Factor of Plastic Film | D 150 | |
| **Elongation of Plastic Film** | D 882 | |
| **Environmental Stress Cracking Resistance** | | |
| of Plastic Film | D1693 | |
| **Flexural Modulus of Plastic Film** | D790 | |
| **Folding Endurance of Paper** | | T423 |
| **Gloss (spectral)** | | |
| of Paper and Paperboard | | T480 |
| of Plastic Film | D 2457 | |
| **Grease Resistance** | | |
| of Flexible Packaging Materials | | T507 |
| **Hardness of Plastic Film, Rockwell** | D 785 | |
| Shore | D 2240 | |
| **Haze of Plastic Film** | D 1003 | |
| **Heat Seal Strength of Plastic Film** | F 88 | |
| **Impact Strength, falling dart of Plastic Film** | D 1709/A | |
| **Melt Index** | D1238 | |
| **Oxygen Permeability of Plastic Film** | D 3985 | |
| **Printability of Polyolefin Film Surfaces** | | T698 |
| **Rheological Properties Using Capillary** | | |
| **Rheometer** | D 3985 | |
| **Specific Gravity** | D 792 | |
| **Stiffness of Paper** | | T451 |
| of Paperboard | | T489 |
| 1% Secant modulus of Plastic Film | D 638 | |

## Appendix 7: (Continued)

## TEST METHODS APPLICABLE TO POLYOLEFIN EXTRUSION COATING RESINS AND THEIR SUBSTRATES

| Property | ASTM Method | TAPPPI Method |
|---|---|---|
| **Surface Resistivity of Plastic Film** | D 257 | |
| **Surface Tension** | | |
| of Paper Substrate | D 724 | T458 |
| of PE and PP | D 2578 | T698 |
| **Tear Resistance** | | |
| of Plastic Film | D 1922 | |
| of Paper | | T414 |
| **Tensile Strength** | | |
| of Plastic Film | D 882 | |
| of Paper and Paperboard | D 828 | T404 |
| **Thermal Conductivity** | C I 77 | |
| **Vicat Softening Point** | D 1525 | |
| **Volume Resistivity of Plastic Film** | D 257 | |
| **Water Absorption of Plastic Film** | D 570 | |
| **Water Vapor Transmission Rate** | | |
| of Paper and Paperboard | | T448 |
| of Flexible Packaging Materials | E 96 | T448 |
| of Flexible Barrier Materials | D 1434 | |
| **Wetting Tension of Polyolefin Film Surfaces** | | T698 |
| **Wetting Tension of Polyolefin film and coated surface via the Mayer rod technique** | | T552 |

## Appendix 8:

| | |
|---|---|
| **Alathon®** | **HDPE Polyethylene Resins** |
| **Aquathene™** | **Ethylene vinylsilane compounds for wire and cable** |
| **Flexathene®** | **Thermoplastic Polyolefin Resins** |
| **Integrate™** | **Functionalized Polyolefins** |
| **Microthene®** | **Powdered polyethylene resins** |
| **Petrothene®** | **Polyethylene and polypropylene resins** |
| **Plexar®** | **Tie-layer resins** |
| **Ultrathene®** | **Ethylene vinly acetate (EVA) copolymer resins** |

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