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# SAFOAM<sup>®</sup> USER'S GUIDE

This 'SAFOAM<sup>®</sup> User's guide' was prepared as a service to the customers using Reedy International Corporation's SAFOAM<sup>®</sup> family of endothermic foaming agents. Reproduction or distribution of this brochure, in whole or in part, is prohibited without the permission of *Reedy International Corporation*.

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# INTRODUCTION

**SAFOAM**<sup>®</sup> is produced from naturally occurring materials that are microencapsulated using sophisticated proprietary technology. Produced under food ingredient conditions with the highest levels of quality control, **SAFOAM**<sup>®</sup> is inherently safe to use and all components are *Generally Recognized As Safe (GRAS)* as prior sanctioned by the Federal Food and Drug Administration.

**SAFOAM**<sup>®</sup> is environmentally friendly. It has no photochemical reactivity or stratospheric ozone depletion potential. It leaves no residue and is free of the environmental concerns commonly associated with existing nucleating agents. **SAFOAM**<sup>®</sup> does not contain any transition metal salts as activators and does not generate cyanuric acid or ammonia, which are toxic and contribute to degradation of mold surfaces and extrusion equipment.

*Reedy International Corp.*, in partnership with Genpak Corporation, has completed development of an advanced foam production process that meets current and future global emission requirements without major equipment changes or compromises in product quality, density or production rates.

This new technology is designed to replace chlorofluorocarbons (CFC's) and hydrochlorofluorocarbons (HCFC's) in the production of polystyrene foam food products. The system negates serious disadvantages of existing processes due to its ability to achieve very efficient production rates while improving the physical properties of the foamed materials.

*Reedy International* and Genpak Corporation have recently been awarded patents for producing foam sheets using **SAFOAM**<sup>®</sup> concentrates and a combination of atmospheric and organic gases as blowing agents. *Reedy International* currently holds six additional patents for using direct gas in a low-density polystyrene foam using CO<sub>2</sub>, N<sub>2</sub>, and/or any other gas.

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# SAFOAM<sup>®</sup> - ITS USE IN THERMOPLASTICS

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**SAFOAM<sup>®</sup>** is an endothermic chemical foaming agent (CFA) used in thermoplastics with a wide variety of applications. Processors use it to produce foamed moldings or extrusions, or to eliminate other processing problems, such as sink marks, warpage or molded in stresses. Its use in structural plastics provides several advantages, including:

- Weight reduction
- Increased part rigidity
- Stress and sink mark elimination
- Cost savings
- Enhanced acoustical and insulation properties
- Warpage elimination

Plastic processing is a constantly evolving industry and new techniques and equipment are introduced regularly. Despite the wide variety of equipment and processes, they can be classified under two main groupings:

- Molding
- Extrusion

This User's Guide reviews physical and chemical foaming agents as well as the basic injection molding and extrusion processes. A glossary of terms and a list of common acronyms appear in the Appendix. **SAFOAM<sup>®</sup>** selection and use information can be found on the insides of the covers.

This **SAFOAM<sup>®</sup>** User's Guide is intended as a service to our customers. The information contained in this guide is based on our experience with **SAFOAM<sup>®</sup>** and the foaming processes that are discussed. We strongly recommend that **SAFOAM<sup>®</sup>** be thoroughly evaluated in your process equipment and application. We do not guarantee favorable results, and we assume no liability in connection with the use of **SAFOAM<sup>®</sup>**. This information is not intended as a license to operate under, or a recommendation to infringe any patent of *Reedy International Corporation* or others.

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# STRUCTURAL PLASTICS AND POLYMER SELECTION

The term “structural foam” is generally used to describe a plastic product having integral skins, a cellular core, and a high enough strength-to-weight ratio to be used in load-bearing applications. There are many systems used in the production of structural foam, with as many equipment manufacturers preparing machines to make the products. There are a wide variety of thermoset and thermoplastic resins used in structural foam, with many types of physical and chemical foaming agents being used to produce the cellular structure.

The real value of foam is the increase in strength-to-weight ratio and the reduction of sink marks in areas opposite thick sections. The structural integrity of a properly foamed part is greatly enhanced due to the reduction of stresses and a general increase in stiffness. Parts produced by the structural foam process are three to four times as rigid as injection moldings of the same weight. The density of a foamed part is generally 60-90% of the polymer or foaming agent.

Foamed plastic can be thermoset, thermoplastic or thermoplastic elastomer resins. Thermosets are generally foamed as a result of the vaporization of a foaming agent, caused by the exotherm in the thermosetting reaction. Foamed thermoplastics are typically produced by the addition of an inert gas or chemical foaming agent to a thermoplastic resin. The most significant quantities of foamed plastics are being produced in thermoplastics. More recently the term “structural plastics” has been adopted to describe polymers foamed by a variety of emerging technologies.

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## PROPERTIES OF AMORPHOUS POLYMERS

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Amorphous polymers are those that are devoid of crystallinity or stratification. They do not have melting points but rather softening ranges. They are normally transparent, and undergo only small volume changes when solidifying from the melt, or when the solid softens and becomes fluid. Most plastics are amorphous at processing temperatures, with many retaining this state under all normal conditions. Common examples of amorphous thermoplastics include polycarbonate, acrylonitrile-butadiene-styrene (ABS) and polystyrene, and are very easy to foam using **SAFOAM**<sup>®</sup>.

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## PROPERTIES OF CRYSTALLINE POLYMERS

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Crystalline polymers contain solid crystals with a definite geometric form. Such structures are characterized by uniformity and compactness. Unlike amorphous polymers, crystalline polymers have considerable order to their molecules in a solid state. This indicates that many of the other atoms are regularly spaced, have a true melting point with a latent heat of fusion associated with the melting and freezing process, and have a relatively large volume change during the transition from melt to solid. It is these characteristics that cause a lack of melt tension and/or melt strength, which may make crystalline polymers more difficult to foam. Common examples of crystalline thermoplastics include polyethylene, polypropylene, nylon, and acetal.

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## PROPERTIES OF THERMOPLASTIC ELASTOMERS

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Thermoplastic elastomers (TPE) represent a family of polymers that resemble elastomers in that they can be repeatedly stretched without distortion of the unstressed part shape. They are, however, true thermoplastics and as such do not require curing or vulcanization as do rubber-like elastomers. It is possible to foam TPEs if they are specifically designed for melt tension and strength.

The desirable performance properties of thermoplastic elastomers are derived from their chemistry and morphology. Thermoset rubber articles commonly contain a reinforcing agent such as carbon black. In TPEs, the polymer system itself provides this reinforcement, commonly due to two or more intermingled polymer systems, each with its own phase.

Chemical composition and morphology provide a rational, convenient means of categorizing the existing commercial thermoplastic elastomers. There are presently six generic categories of commercial TPEs:

- 1) Styrenic block copolymers
- 2) Rubber-polyolefin blends
- 3) Elastomeric alloys
  - a) Thermoplastic vulcanizates (TPVs)
  - b) Melt processible rubbers (MPRs)
- 4) Thermoplastic polyurethanes
- 5) Thermoplastic copolyesters
- 6) Thermoplastic polyamides (nylons)

# STRUCTURAL PLASTICS AND POLYMER SELECTION

To compare the different classes of TPEs, locate them on the two-dimensional plot below, with the horizontal axis representing performance and the vertical axis representing cost. The cost and performance of the generic categories of TPEs increase as one proceeds in the order of styrenics, polyolefin blends, elastomeric alloys, polyurethanes, copolyesters, and polyamides. As a basis for comparison, Table 2 gives a plot of the different generic classes of thermoset rubbers. The thermoset rubbers also increase in both cost and performance as one proceeds from the lower left to the upper right portion of the plot. In comparing thermoplastic rubbers with the corresponding thermoset rubbers, it is important to remember the processing costs of the TPEs are significantly lower than those of the thermosets.

## Thermoplastic Elastomers.

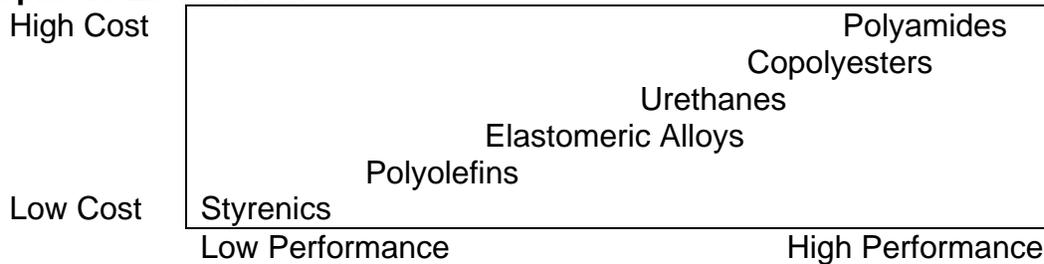


Table 1.

## Thermoset Rubbers.

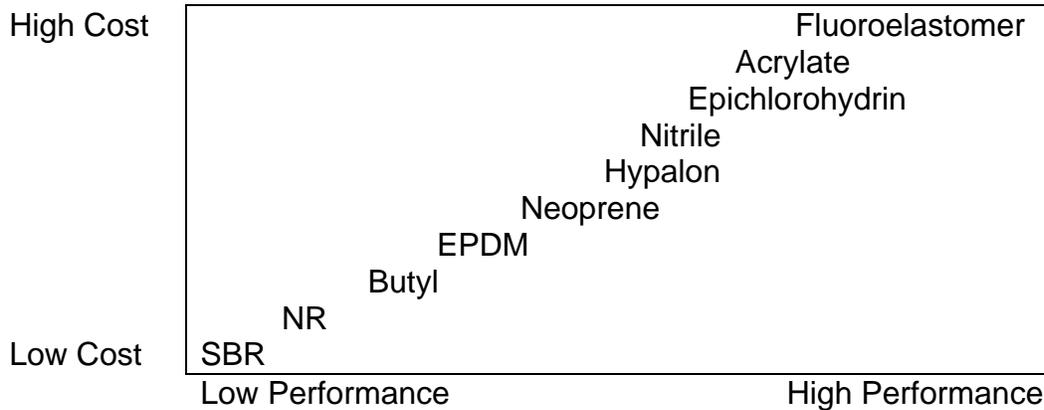


Table 2.

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# FOAMING AGENT SELECTION

Any substance capable of producing a cellular structure in a plastic or rubber mass, be it alone or in combination with other substances, is defined as a *foaming agent*. Thus, the term includes compressed gases that expand when pressure is released, soluble solids that leave pores when leached out, liquids that develop cells when they change to gases, and chemical agents that decompose or react under the influence of heat to form a gas. Liquid foaming agents include certain aliphatic and halogenated hydrocarbons, low boiling alcohols, ethers, ketones, and aromatic hydrocarbons. The chemical foaming agents range from simple salts such as ammonium or sodium bicarbonate to complex nitrogen releasing agents, of which azodicarbonamide is an important example. Foaming agents, also known as chemical blowing agents (CBAs), can be utilized in all conventional plastic processes including extrusion, calendaring, injection and compression molding, coating, expansion casting, and rotational molding. Regardless of type, a foaming agent should possess the following desirable qualities:

1. Long term storage stability under normal conditions.
2. Gas release over a controlled time and temperature range.
3. Low toxicity, odor, and color of both the foaming agent and its decomposition products.
4. No deleterious effects on the stability and processing characteristics of the polymer.
5. The ability to form cells of uniform size.
6. The ability to produce a stable foam, that is, the gas must not be lost from the cell, which causes collapse.
7. Good cost-performance relation and availability.

The quantity of gas contained in a foaming agent is not nearly as important as the rate at which that gas is released. Azodicarbonamides contain large volumes of gas, but are well known to give rise to foamed parts with voids and poor surface finish. **SAFOAM**<sup>®</sup> endothermic foaming agents contain less gas volume, but release that gas in a much more controlled fashion, giving rise to more uniform cell structures. **SAFOAM**<sup>®</sup> produces CO<sub>2</sub>, which is a low-pressure, very soluble gas. Solubility improves the melt flow of most polymers and may lower processing temperatures. These foamed plastics have higher performance characteristics than those generated with other commonly available foaming agents.

Foaming agents are classified as physical or chemical. Chemical foaming agents (generally solids) undergo a chemical reaction when producing the gas, while liquid physical foaming agents undergo a reversible change of physical state: vaporization.

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### PHYSICAL FOAMING AGENTS

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The two major categories of physical foaming agents are liquids and gases. The gas most often used is compressed nitrogen. In injection molding, the gas is injected under high pressure directly into the polymer during plastication, and the mixed polymer and gas are metered into the mold. When the pressure is relieved, the gas becomes less soluble in the polymer and expands, forming the cellular structure. Nucleating agents like **SAFOAM**<sup>®</sup>, in the form of finely divided powders and chemical foaming agents, sometimes are used with the gas to yield a finer cell structure. The nitrogen is inert, nonflammable, leaves no residue in the polymer, and is not temperature restrictive; however, the use of the process in industry is limited. The specialized equipment that is needed is licensed, and there is a tendency for the process to produce foams with coarser cell structure and poorer surface appearance than those of polymer processes with nitrogen-producing chemical foaming agents.

Liquid physical foaming agents produce gas through vaporization. They are generally short-chain aliphatic hydrocarbons (in the C5 to C7 range) and their chlorinated and fluorinated analogs. Others used less frequently include cycloaliphatic and aromatic hydrocarbons, alcohols, ketones, and aldehydes. The liquid physical foaming agents are used over a wide temperature range in low pressure atmospheric processes. They are widely used to produce low density thermoplastics such as foamed polystyrene, and thermoset polymers such as polyester, epoxy, and polyurethane foam systems.

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### CHEMICAL FOAMING AGENTS

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Chemical foaming agents produce gas by a chemical reaction, such as a thermal decomposition or a reaction between two or more components. They are selected for a specific application or process based on their decomposition or gas generation temperature. It is important to match the decomposition temperature with the processing temperature of the polymer to be foamed. If the polymer processes at temperatures below that of the chemical foaming agent, little or no foaming will occur. Additionally, if the process temperature is significantly above the foaming agent's decomposition or reaction temperature, poor (overblown, ruptured) cell structure and surface skin quality problems will likely result.

Chemical foaming agents may be either organic or inorganic chemicals. The thermodynamics of gas formation with chemical foaming agents are classified as either *exothermic* (heat releasing) or *endothermic* (heat absorbing). The most well known organic, exothermic chemical foaming agent is azodicarbonamide. The most common inorganic, endothermic foaming agent is sodium bicarbonate.

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## EXOTHERMIC CHEMICAL FOAMING AGENTS

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### Azodicarbonamide

One of the most widely used exothermic chemical foaming agents is azodicarbonamide. This chemical foaming agent is a yellow powder that decomposes at 383-421°F (195-216°C), depending on the method of preparation. It evolves 220 cc/gram of gas after decomposition. The decomposition rate of azodicarbonamide can be adjusted by activators, and a wide range of lower decomposition temperatures can be attained. This range of useful temperatures and high gas efficiency are the primary advantages of this type of chemical foaming agent. Suitable activators include transition metal salts, (especially those of lead, cadmium and zinc), polyols, urea, alcohol amines, and some organic acids. Unlike many other organic foaming agents, azodicarbonamide does not support combustion.

The thermal decomposition of azodicarbonamide is complex, giving rise to a variety of reaction products. The decomposition of azodicarbonamide at 374°F (190°C) produces gaseous products consisting of nitrogen (65%), carbon monoxide (31.5%), and carbon dioxide (3.5%). Ammonia has also been detected in some cases.

Exothermic chemical foaming agents are generally used for the following results:

- maximize total density reduction
- generate foam in high viscosity resins
- increase mold filling capability
- decompose at higher temperatures

Azodicarbonamides are capable of generating large quantities of gas at high foaming pressures. The exothermic reaction of this family of chemical foaming agents is hard to control in most foaming applications. This leads to coarser cell structures, voids, and poorer surface quality for the processed parts. The thermal decomposition of azodicarbonamide compounds is well known to generate cyanuric acid and isocyanurate, which contribute to plate out on mold surfaces and extrusion equipment.

## FOAMING AGENT SELECTION

Exothermic azodicarbonamide chemical foaming agents should be used only when an endothermic chemical foaming agent is judged as unsuitable for your application.

A Differential Scanning Calorimetry curve for a common exothermic azodicarbonamide chemical foaming agent can be found in Figure 1.

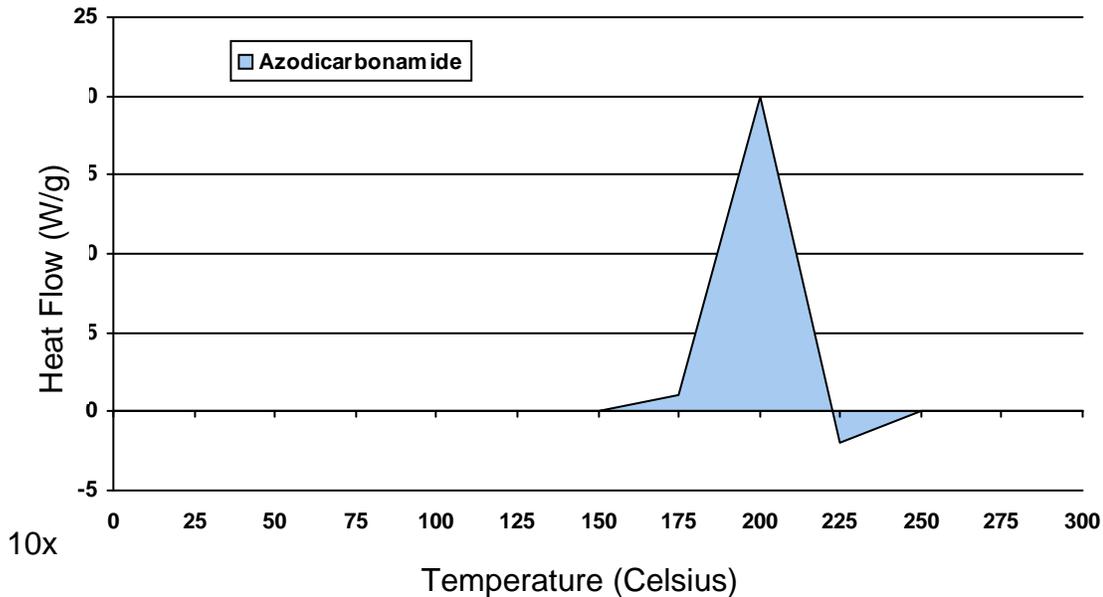


Figure 1. Differential Scanning Calorimetry curve for a common azodicarbonamide chemical foaming agent showing exothermic behavior.

## ENDOTHERMIC CHEMICAL FOAMING AGENTS

### Sodium Borohydride

Chemical foaming agents based on sodium borohydride produce gas as a result of a chemical reaction rather than thermal decomposition. Sodium borohydride foaming agents produce copious amounts of hydrogen gas upon reaction with water or when activated by a proton source. The decomposition of sodium borohydride is independent of processing temperatures.

Several products based on sodium borohydride exist in polyethylene and polystyrene carriers. Some grades are activated by special chemical additives. The sodium borohydride concentrates are typically 5-10% active. The sodium borohydride foaming agents are stable to moisture once compounded in the concentrate form.

Because the reaction decomposition product of sodium borohydride foaming agents is hydrogen gas, extreme care must be taken not to exceed the lower explosion limit of 4% volume of hydrogen in the air.

### Traditional Acid/Carbonate Systems

The most well known endothermic chemical foaming agents are from the acid/carbonate family. These foaming agents take advantage of the chemical reactivity of inorganic carbonates with acidic species to evolve carbon dioxide gas. The most widely used acid/carbonate systems are based on sodium bicarbonate and citric acid derivatives.

The common acid/bicarbonate products are available as 100% powders or as concentrates in universal waxy-type carriers. The concentrate products are available in up to 70% active concentrates. The gas evolution of these acid/carbonate products depends on the level of their activity and in which form the product is used. The typical 100% active powder product produces about 100 cc/gram of carbon dioxide gas.

The acid/carbonate systems are typically safe for use in food contact applications. All components are Generally Recognized As Safe (GRAS). The carbon dioxide gas is non-flammable and poses no threat for explosion. It readily diffuses from the foamed products, allowing for shorter painting cycles. The universal waxy-type carriers have been known to cause screw slippage in certain applications. Poor dispersion is a common concern for the high percentage concentrates in many traditional material handling systems. Poor dispersion lends itself to variations in the foaming process, creating voids and thin skins that lead to mechanical failure in the final foamed products.

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## SAFOAM<sup>®</sup> ENDOTHERMIC CHEMICAL FOAMING AGENTS

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A recent addition to the array of endothermic chemical foaming agents is the **SAFOAM<sup>®</sup>** family of products. The chemistry of **SAFOAM<sup>®</sup>** most closely resembles the traditional acid/carbonate systems, but is based on a buffered salt reaction chemistry. **SAFOAM<sup>®</sup>** products are not solely based on simple sodium bicarbonate, but take advantage of the controlled reaction of synthetic inorganic carbonate compounds with acidic species to generate carbon dioxide gas. Although the volume of evolved gas for **SAFOAM<sup>®</sup>** is somewhat lower than other acid/carbonate systems, the kinetics of gas release insures its superior performance.

**SAFOAM<sup>®</sup>** products are available as 100% active powders or as concentrates in functional polymer carriers. The concentrates are typically 40% active to insure a good dispersion in traditional material handling systems. **SAFOAM<sup>®</sup>** P, FP, RIC, and RPC will produce about 140 cc/grams and serve as the base material for the polyethylene and polystyrene concentrates.

A Differential Scanning Calorimetry curve of a common endothermic chemical foaming agent can be found in Figure 2.

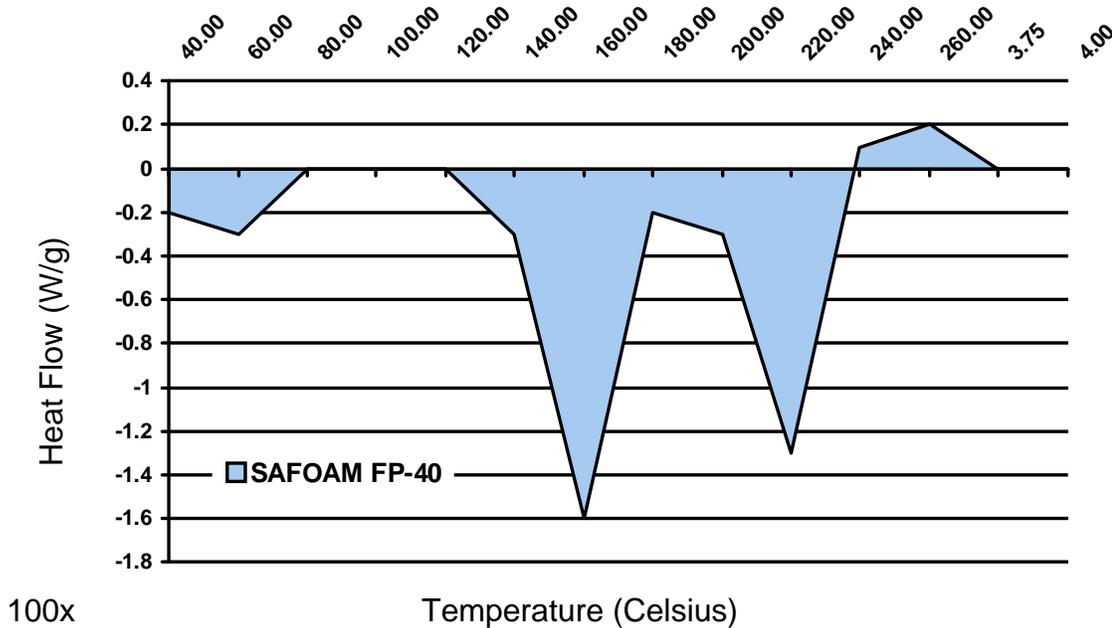


Figure 2. Differential Scanning Calorimetry curve for **SAFOAM**<sup>®</sup> FP-40 showing endothermic behavior.

The use of **SAFOAM**<sup>®</sup> endothermic chemical foaming agents gives rise to more uniform cell structures, thicker skins, better surface appearance, and more control as compared to other traditional chemical foaming agents. **SAFOAM**<sup>®</sup> affords significant weight reduction, sink mark elimination, shrinkage control, and warpage elimination. It produces parts that can be painted without significant degassing time.

**SAFOAM**<sup>®</sup> products are safe for use in food contact applications. The components of all **SAFOAM**<sup>®</sup> products are Generally Recognized As Safe (GRAS). **SAFOAM**<sup>®</sup> is manufactured within the confines of an FDA approved facility, adhering to strict Good Manufacturing Practices to insure the maximum product quality.

**SAFOAM**<sup>®</sup> products are generally used to:

- improve nucleation in tandem with nitrogen
- create a uniform cell structure
- reduce cycle time
- reduce surface swirl or splay appearance
- foam highly fluid polymers
- reduce physical property loss
- minimize part stresses
- increase weld line strengths

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### GAS EVOLUTION AND RATE

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The enhanced performance of **SAFOAM**<sup>®</sup> endothermic chemical foaming agents is believed to be the result of a more uniform cell structure that is directly related to the controlled rate of gas release in the product. This rate of gas release is dependent on temperature, pressure and the composition of the foaming agent. The **SAFOAM**<sup>®</sup> family of endothermic chemical foaming agents is based upon modified citric acid/carbonate systems that vary significantly in their compositions from the traditional acid/carbonate systems.

The gas released by **SAFOAM**<sup>®</sup> FP can be seen in Figures 3 and 4, while figures 7 and 8 represent **SAFOAM**<sup>®</sup> FP-40. A typical azodicarbonamide was used as a reference in Figure 3. The gas volume data was generated by a linear temperature program. The thermal expansion of the air in the sample vessel is accounted for by the subtraction of a blank value (45.7cc) from the total gas volume measured. Figure 3 clearly shows that **SAFOAM**<sup>®</sup> FP generates 200 cc/gram of gas volume at 350°C. Figure 7 shows that **SAFOAM**<sup>®</sup> FP-40 generates 101 cc/gram at 375°C. Both the **SAFOAM**<sup>®</sup> FP and FP-40 generate significantly less gas than the typical azodicarbonamide, which generates 230 cc/grams at 350°C.

The first order kinetic factor of **SAFOAM**<sup>®</sup> RPC as compared to a typical azodicarbonamide can be found in Figure 6. The differential response of **SAFOAM**<sup>®</sup> RPC is significantly slower than the azodicarbonamide. The longer the foaming time (defined as the amount of time it takes to generate 63% of its gas capacity), the slower the kinetics of gas release. Slower gas release allows for a more controlled formation of the cell structure within the foamed plastic, which in turn allows for fewer voids and stresses, thicker skins, and higher quality surface finishes.

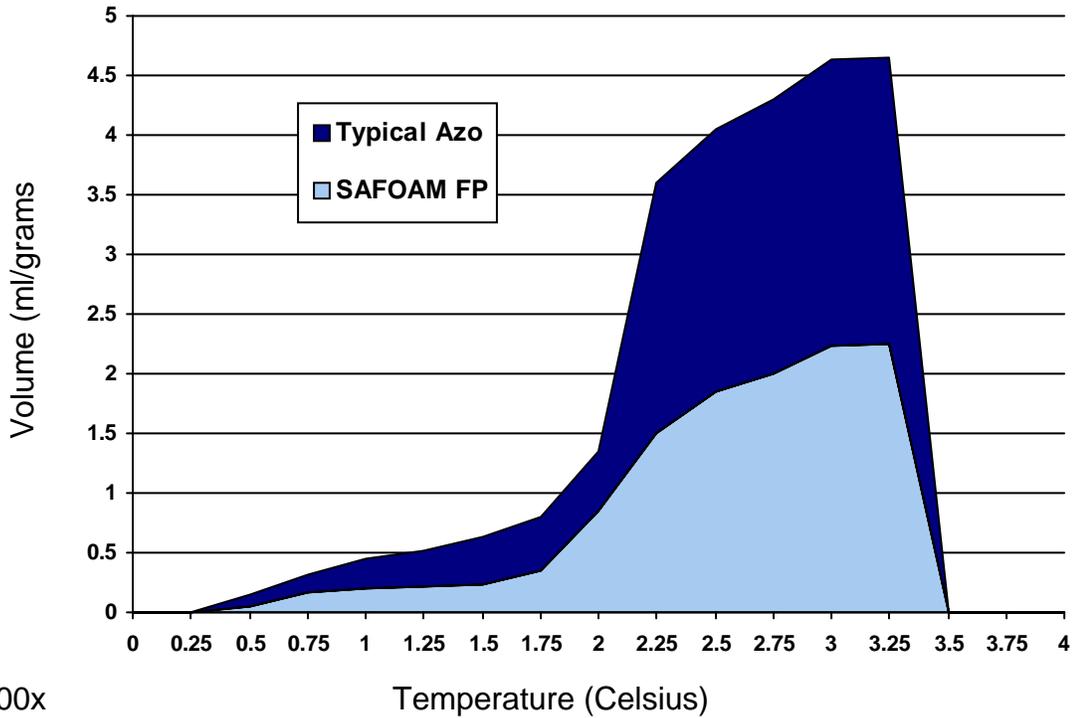


Figure 3. Comparison of gas volumes for SAFOAM® FP and a typical azo-dicarbonamide.

100x

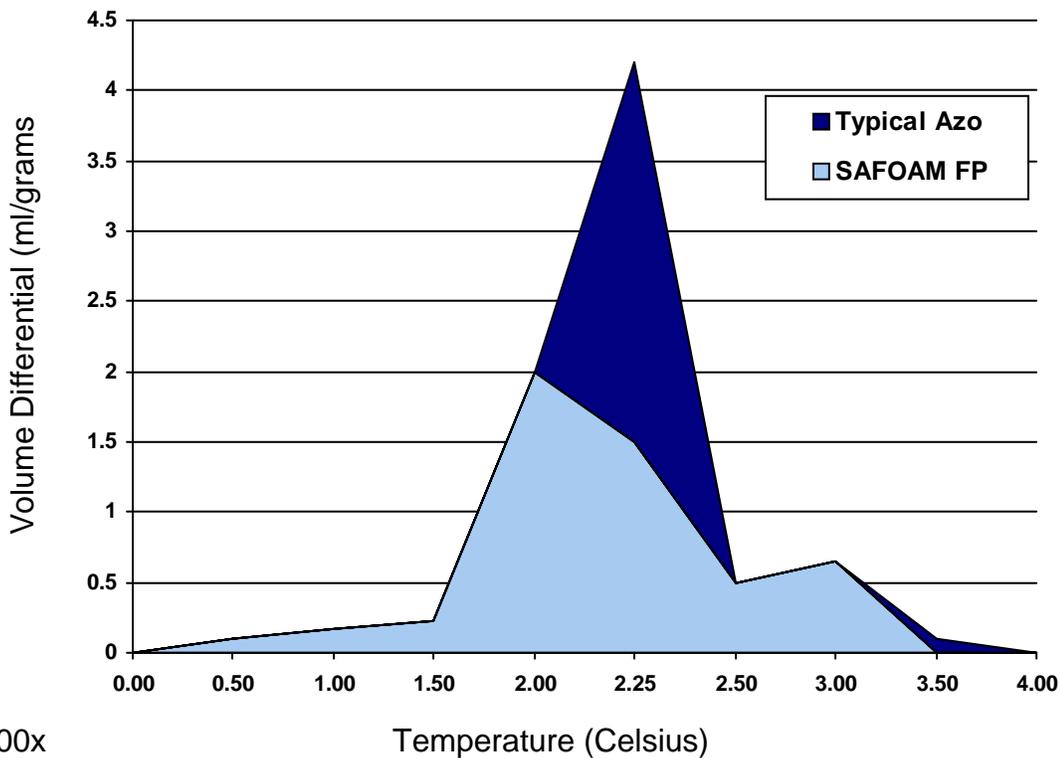


Figure 4. Differential response for SAFOAM® FP and a typical azodicarbonamide showing rate of gas release.

100x

# FOAMING AGENT SELECTION

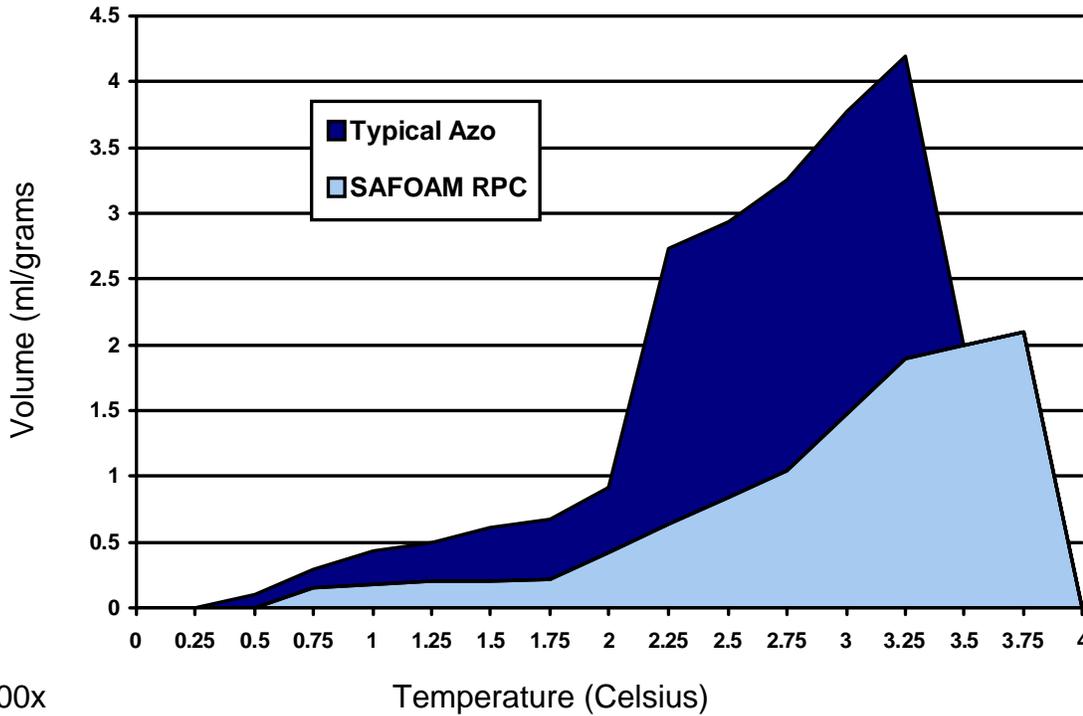


Figure 5. Comparison of gas volumes for SAFOAM® RPC and a typical azodicarbonamide.

100x

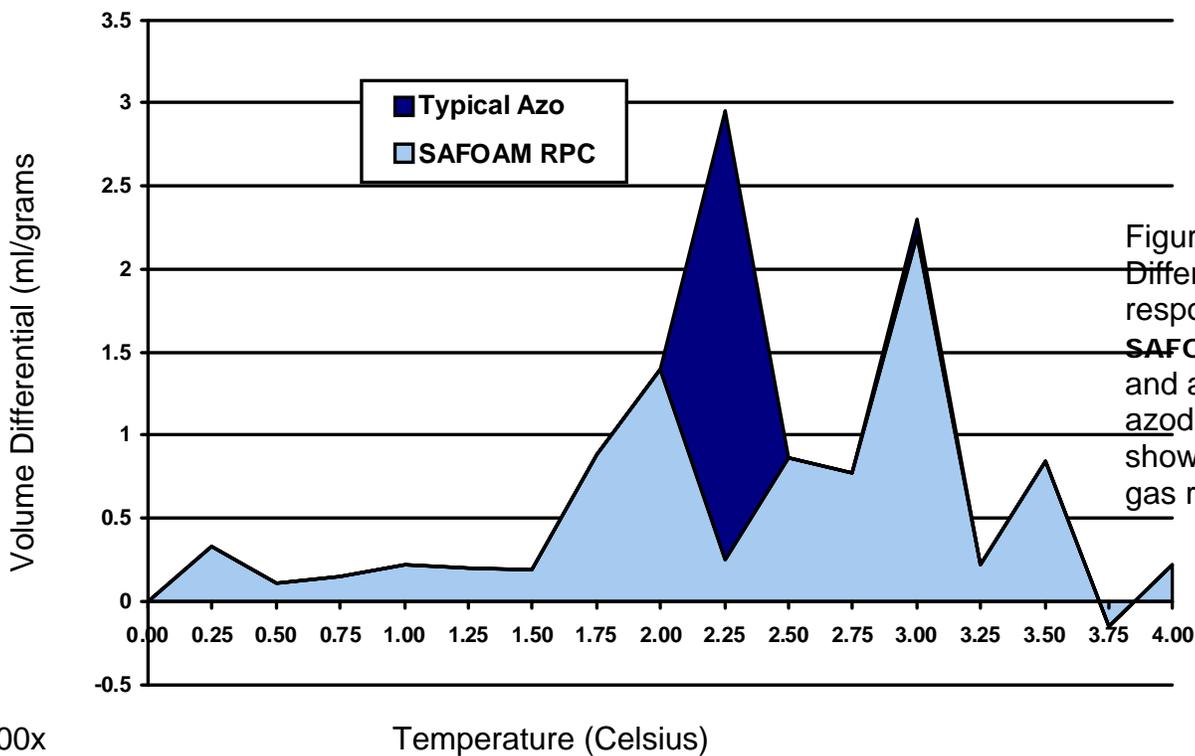


Figure 6. Differential response for SAFOAM® RPC and a typical azodicarbonamide showing rate of gas release.

100x

# FOAMING AGENT SELECTION

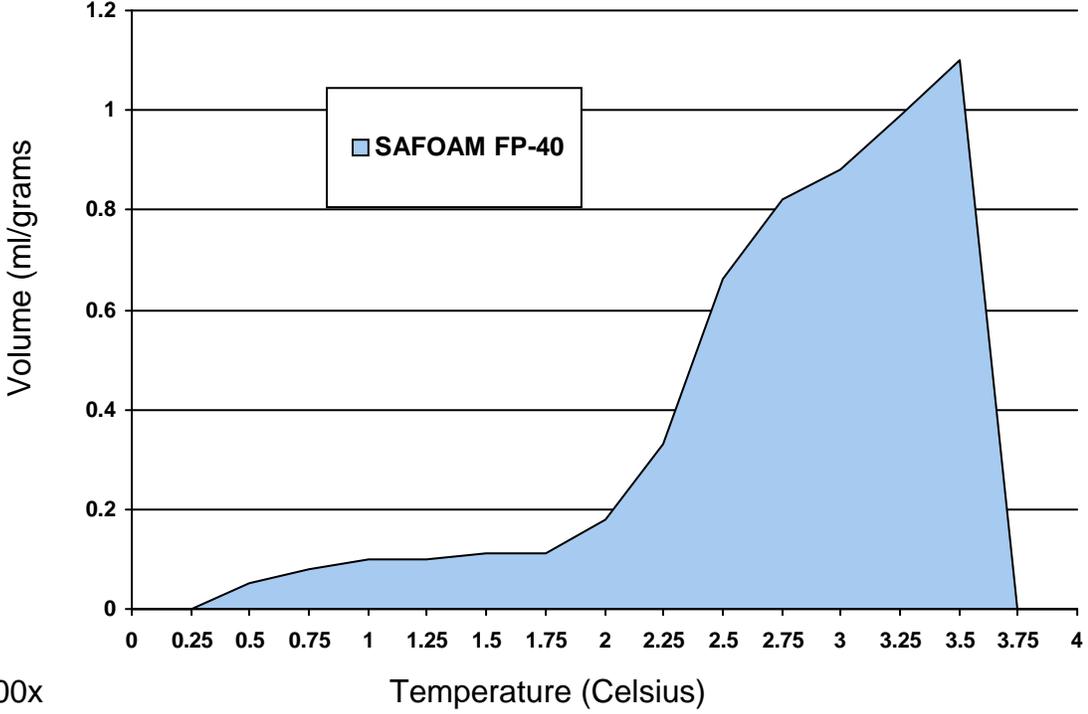


Figure 7. Gas volume for SAFOAM® FP-40.

100x

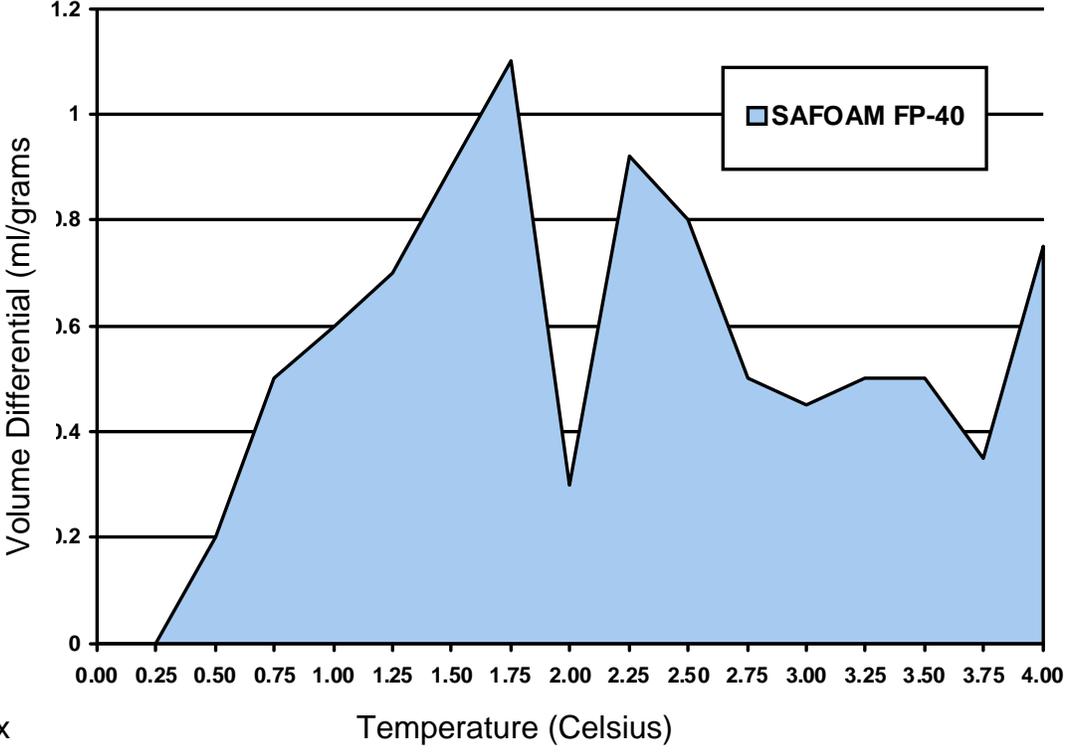


Figure 8. Differential response for SAFOAM® FP-40 showing rate of gas release.

100x

**SAFOAM®** chemical blowing agents (CBAs) are sophisticated endothermic additives that provide a number of processing advantages for profile extrusion, co-extruded foam pipe products and foam sheet producers. **SAFOAM®** concentrates utilize melt flow enhancers and impact modifiers to create a very fine cell structure, resulting in improved physical properties. Although **SAFOAM®** concentrates allow foam production processes to meet current and future global emission requirements, they also provide important advantages in production economics. The use of **SAFOAM®** reduces raw material requirements, improves extrusion rates, reduces cycle time and lowers material scrap and rework.

Extruded thermoplastics can be foamed to 50% or more of their original densities. Foaming may take place during extrusion or during post-forming operations such as thermoforming, blow molding, or laminating.

Successful extrusion of foamed plastics with density reduction of 10% or more depends upon adjusting temperature and pressure profiles within the extruder to efficiently use **SAFOAM®**. The temperature at the rear zones should be low enough to prevent premature decomposition of **SAFOAM®** in the barrel; otherwise gas loss may occur back through the hopper. Since **SAFOAM®** produces only odorless carbon dioxide, its presence cannot be detected. The melt temperature should increase rapidly towards the die to increase the decomposition rate of the **SAFOAM®**.

Enough pressure must be maintained on the melt to prevent foaming in the extruder as **SAFOAM®** decomposes. This can be achieved by use of a high compression screw, or temperature reduction in the front extruder zones to produce a backpressure. Pressure can also be regulated by adjusting the screw speed. Die temperature is normally lower for unfoamed plastics to enhance surface appearance.

### Overview

Foam extrusion is a complex process with many interrelated variables. As a continuous, dynamic process, a change in any one variable has a ripple effect that extends to the final product. Understanding the variables and learning how to control them is the best route to producing a high quality product with the best economic costs.

One producer of foam sheet for semi-rigid food packaging who utilized **SAFOAM®** concentrates was able to significantly improve production costs in several areas. They were able to achieve an additional 15% reduction in part weight while maintaining important physical properties such as rigidity and strength. In addition to savings in resin costs per unit, they were able to reduce the amount of physical blowing agents needed by 20%. Because of the fundamental chemistry of **SAFOAM®** concentrates, both extruder and thermoforming output rates increased by over 20%. These performance improvements resulted in lower equipment costs per unit and made the multi-plant operation a highly competitive producer.

A producer of co-extruded foam pipe has used **SAFOAM®** concentrates to achieve a 6% greater reduction in density over an alternative foaming process which resulted in almost 9% net savings in resin cost. In addition, increased extrusion rates lowered direct equipment operating costs per foot by almost 20%. They also reported improvement in physical properties and the consistency of **SAFOAM®** had reduced scrap and rework.

## EXTRUSION EQUIPMENT

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### Extruders - Basic Operation and Process

The process by which a solid plastic pellet or powder is transformed by heat and pressure into a molten continuous form is called extrusion. In order to perform this operation an extruder is used to effect this transformation. The process is as follows:

The resin is fed from the hopper onto the screw, heated, melted and pumped forward, by the rotation of the screw, in a continuous action through an orifice into a desired shape. All of this is accomplished continuously with no breaks or stopping. Once the extrudate has left the extruder, it is then sized, cooled and cut to length.

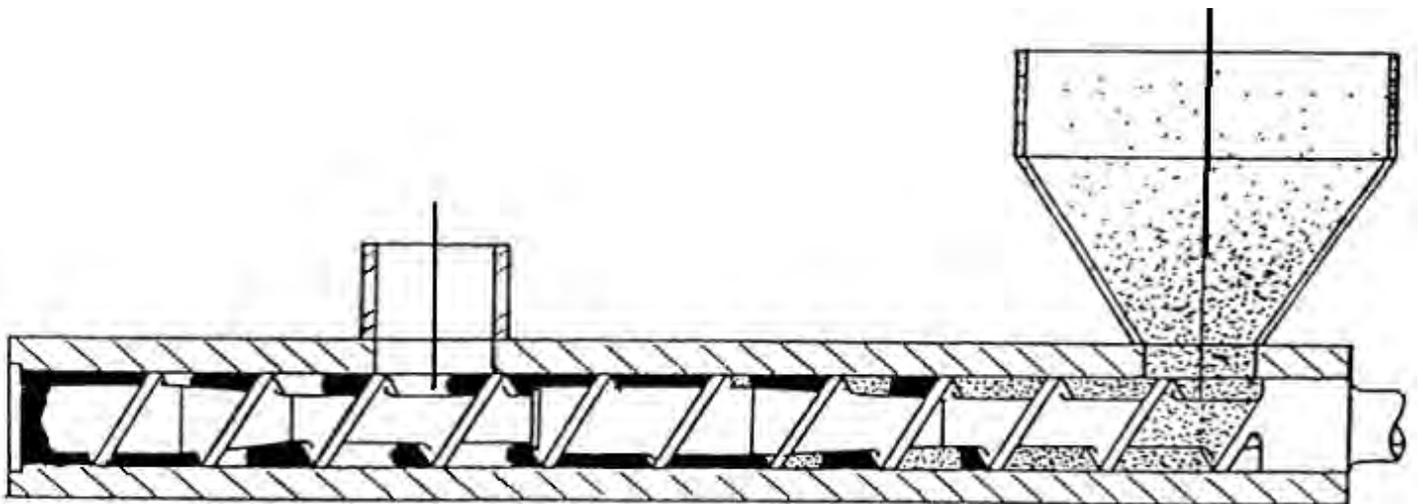


Figure 9

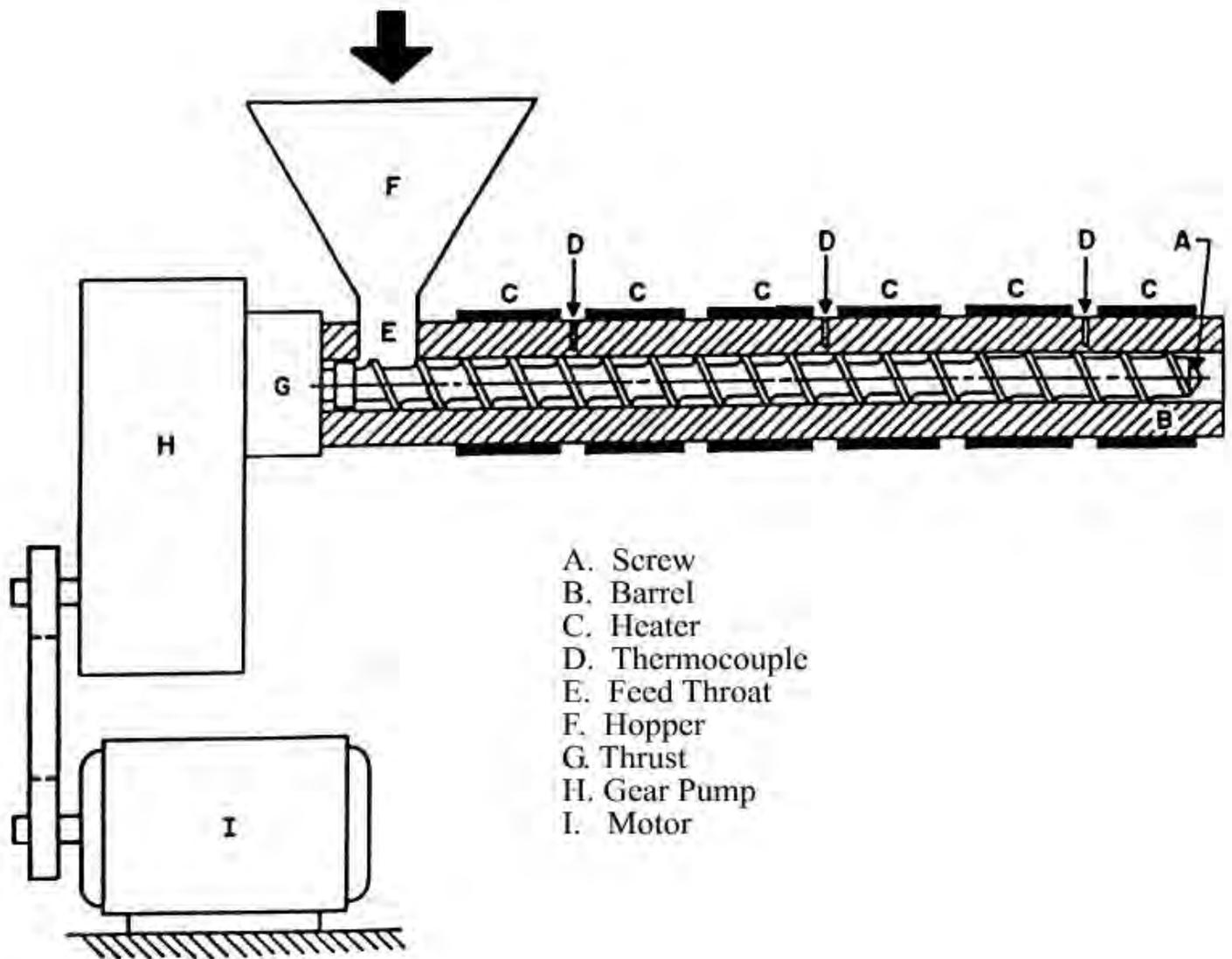


Figure 10

The extruders used in these extrusion processes for the production of foamed profiles, sheet, and tubing of rigid PVC using CBAs are the same as those used to produce unfoamed rigid PVC. They may be of single-screw or twin-screw configuration. Single-screw extruders that have proven effective for powder processing are two- and three-zone screw drives with lengths of 25 to 28 diameters and a flight depth ratio in the range between 2:1 and 2.5:1.

### Hopper

This funnel is where the resin is loaded in either pellet or powder form and is typically gravity fed into the feed throat of the extruder. It is mounted on the feed throat casting. They are usually equipped with a sight/level glass window, discharge chute and sliding shut off gate.

## Feed Throat

The feed throat is where the resin is directed onto the feed section of the screw. It is machined into a casting, which is located at the rear of the extruder between the gear housing and barrel. The casting is cored for water-cooling to prevent the resin from sticking together or “bridging”. Resin will pick up transfer heat from the barrel. Care must be taken on how the water is regulated into and out of the casting. It should be valved on the inlet side and free flow on the discharge side. This is to prevent a pressure build-up inside of the casting which could damage the casting.

## Barrel

The barrel houses the screw and permits the screw to turn freely. It is constructed of steel and has a hardened liner. It is equipped with heater bands and thermocouples which are controlled and monitored by a controller located in a central control cabinet. Depending on the type of controller and its sophistication, heating and cooling cycles will vary. The barrel is also equipped with cooling to maintain a temperature set point. It can be either forced air cooling or recirculated cold water.

Barrels are specified by two major dimensions: inside diameter and the length of the barrel. Typical extruder inside-diameter sizes are 1½, 2, 2½, 3½, 4½ and 6 inches. The length of the barrel is specified as L/D or "length to diameter ratio", and this is expressed as 24/1, 30/1, 32/1, etc. This ratio of L/D means that (X) inside barrel diameter X (Y) 24, 30, 32, etc. = barrel length.

2½"	X	24	----	60"	(5 ft.)
3½"	X	30	----	105"	(8 ft. 9 in.)
1¼"	X	32	----	40"	(3 ft. 4 in.)

Depending on the extruder manufacturer, the L/D ratio will be calculated either in front of or behind the feed throat.

Some applications require a vent port in the barrel to remove gasses or “volatiles” which occur due to moisture, a by-product or entrapped air. Usually a vacuum pump is connected to aid in the removal of these gasses.

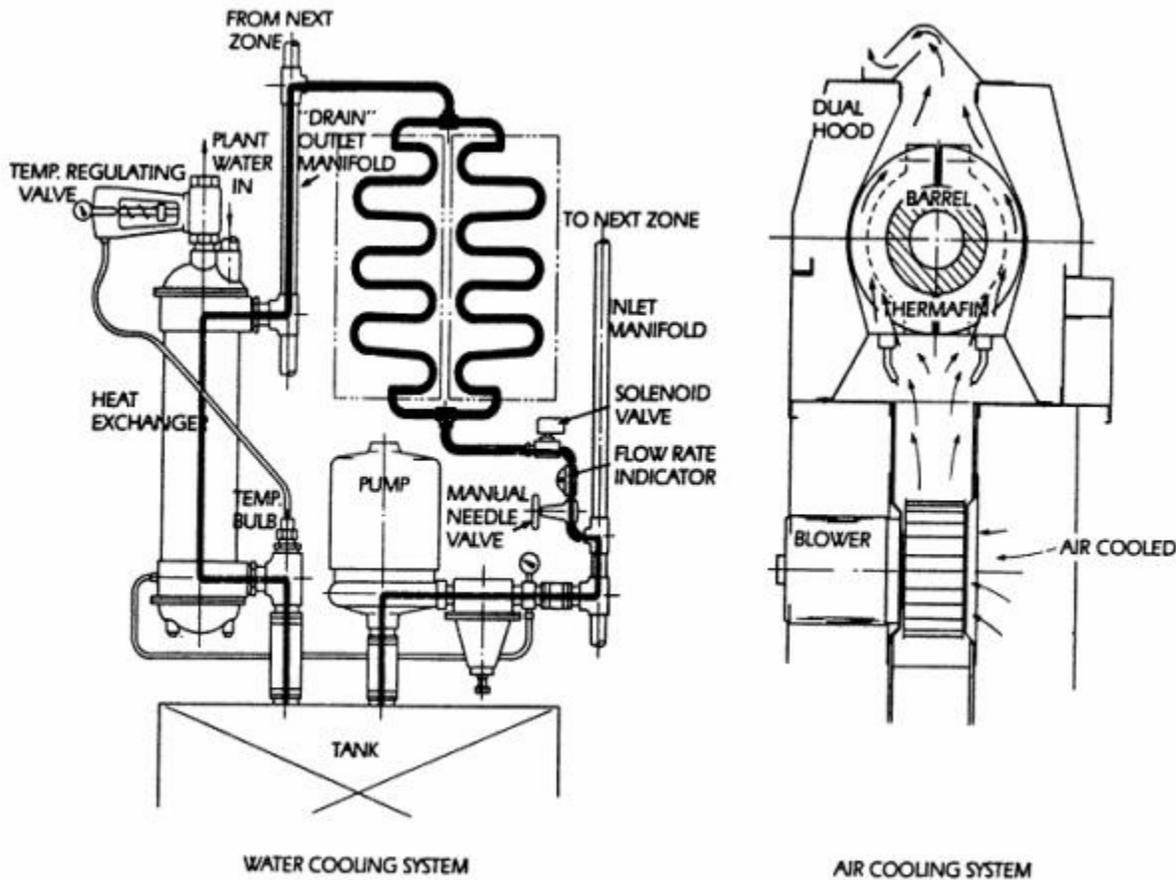


Figure 11

### Screw

The screw is the primary method of pumping/conveying and transforming the resin pellet/powder into a homogeneous melt.

Conventional screws are divided into three distinct working segments; feed section, transition section and metering section and are often referred to by compression ratio. The compression ratio is specified by the depth of the channel in the feed section compared to the depth of the channel in the metering section. A feed depth of .400 and a metering depth of .160 would be classified as a 2.5/1 compression ratio screw.

As the resin is conveyed along the screw it is softened by transfer and frictional heat. The frictional heat is a result of the resin sticking to the barrel wall and being sheared by the screw flight and will eventually fill the channel and be pumped forward.

Because of the varying rheologies of the different resins, different screws are required to achieve optimal physical properties, pounds per hour, and homogeneous melt.

Screws can be cored or “hollowed out” to permit cooling or heating of the tip or body to get a uniform flow of melt at the tip, which prevents uneven center flow.

A conventional single-stage, unvented screw should be used. For adequate mixing of resin and SAFOAM®, the L/D ratio of the screw should be at least 16:1. To prevent premature expansion, it is essential to maintain backpressure. The best options for obtaining backpressure are normally achieved with a high compression screw (2.2 - 3.0 compression ratio), or increasing screw speed.

The extruders used in these extrusion processes for the production of foamed profiles, sheet, and tubing of rigid PVC using CBAs are the same as those used to produce unfoamed rigid PVC. They may be of single-screw or twin-screw configuration. Single-screw extruders that have proven effective for powder processing are two- and three-zone screw drives with lengths of 25 to 28 diameters and a flight depth ratio in the range between 2:1 and 2.5:1.

## Screen Packs

A screen pack of 20-40-20 mesh is common to prevent contamination, if backpressure is to be raised.

## Breaker Plate

In order to transform pellets into a homogeneous hot melt, backpressure must be created along with heat, frictional and transfer by using a breaker plate the backpressure is stabilized and maintained, and at the same time the melt is broken up prior to entering the die body.

The breaker plate can be equipped with the screens to filter out contamination. Screens are specified by mesh size, i.e. 20, 40, 60, 80, etc. Depending on the polymer being run, different screen combinations will be used.

Breaker plates also act as seals between the extruder flanges and die body.

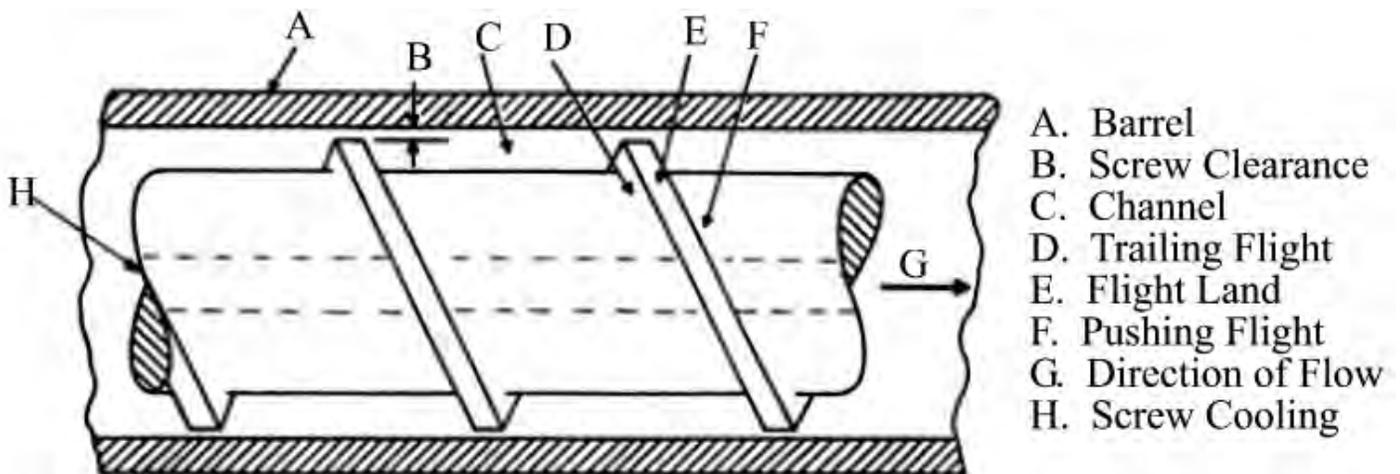


Figure 12

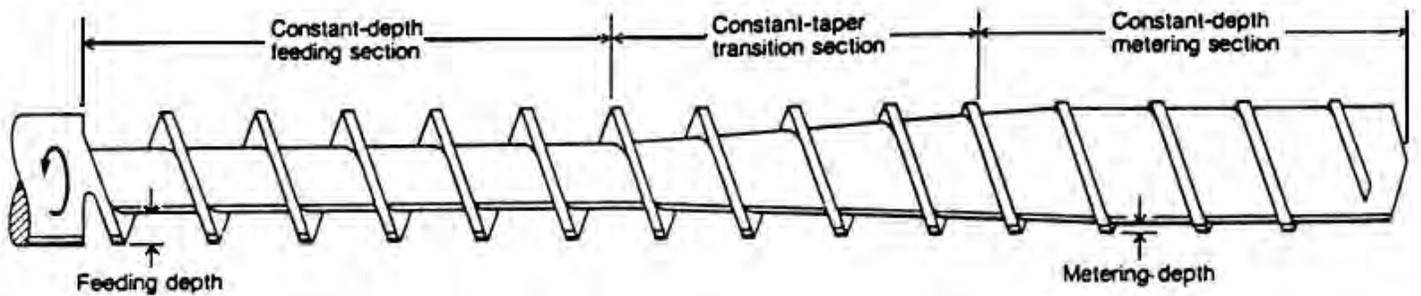
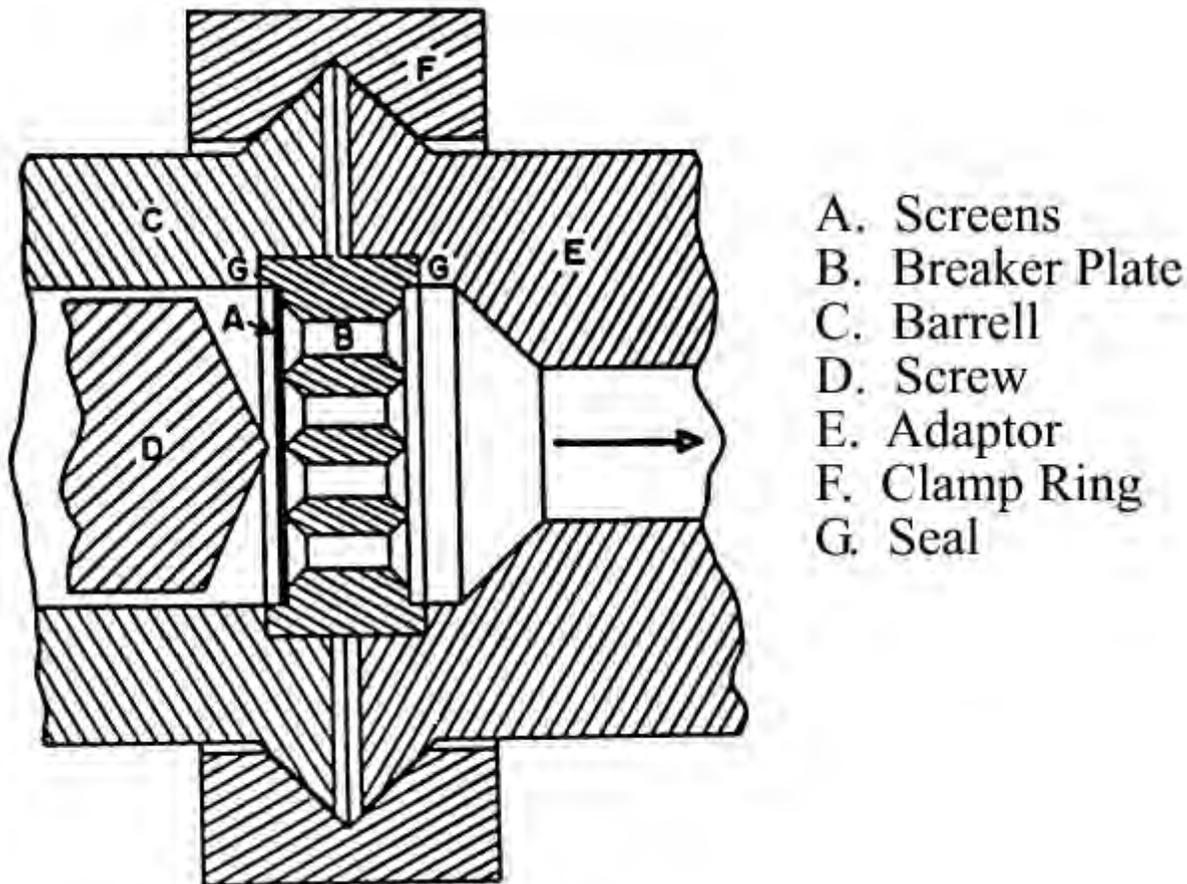


Figure 13



- A. Screens
- B. Breaker Plate
- C. Barrell
- D. Screw
- E. Adaptor
- F. Clamp Ring
- G. Seal

Figure 14

**Drive Motor/Gear Reducer/Thrust Bearing**

Extruder screws are powered by electric motors that have been geared-down to a prescribed screw speed range for a particular resin. Depending on the design of the screw and the screws RPMs the molten resin will be pumped at varying rates.

Different speed ranges are achieved by changing belts and sheaves. Increasing and decreasing the size of the sheaves will change the screw RPM range.

As the screw is rotated, at any RPM, and molten resin is being pumped forward, a backwards force or thrust is exerted. This pressure is absorbed by the thrust bearings.

## Extruder Tooling

The sole function of the extruder is to convert solid resin into a homogeneous melt and pump it continuously through the profile die body and die plate.

As the melt exits the extruder it must be directed and transitioned towards the shape it will take on. The internal design and material(s) of construction must be selected carefully to match the resin being run, i.e.

Polyethylene	Tool steel, hardened & polished
Polypropylene	Tool steel, hardened & polished
Flexible PVC	Stainless Steel, Tool Steel - Ni, Chrome Plated
Rigid PVC	Tool Steel - Ni, Chrome Plated
Styrene	Tool Steel, hardened & polished

There is no such thing as a universal die, therefore serious thought must be given to the choice of resins to be run, with special focus on prioritizing them in order of requirements and then designing the die body. A custom extruder may use the same die body to run P.E., styrene and rigid PVC profiles. It is therefore necessary to design the die body around the rigid PVC.

The internal design of a die is not straightforward or predetermined by any set formula but is often dictated by the resin formula being run. Slight changes in the base formula could change the resin flow, which may require die modification.

For shear and high sensitive material it is necessary to streamline the internal design to direct the flow quickly and efficiently in and out of the die body. Thought must be given so as not to build in dead zones, which will promote stagnation, which will cause color development, degradation, etc.

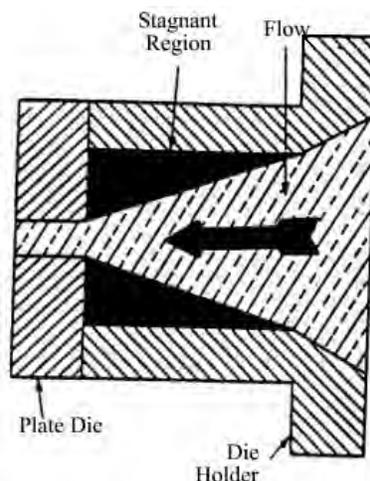


Figure 15

Another very important area of concern is the design of the profile die plate. At first glance the die plate is basically a piece of metal with a profile shape cut through to give the molten resin shape. However, this is not the case. There it must also be given serious thought in its design. Like the die body, polymer flow, rheology, part design and die plate proportions are critical.

It is important to have streamlined design to promote smooth flow. Anywhere the polymer melt is allowed to stagnate: right angle bends, sharp corners, etc. will promote degradation and color development.

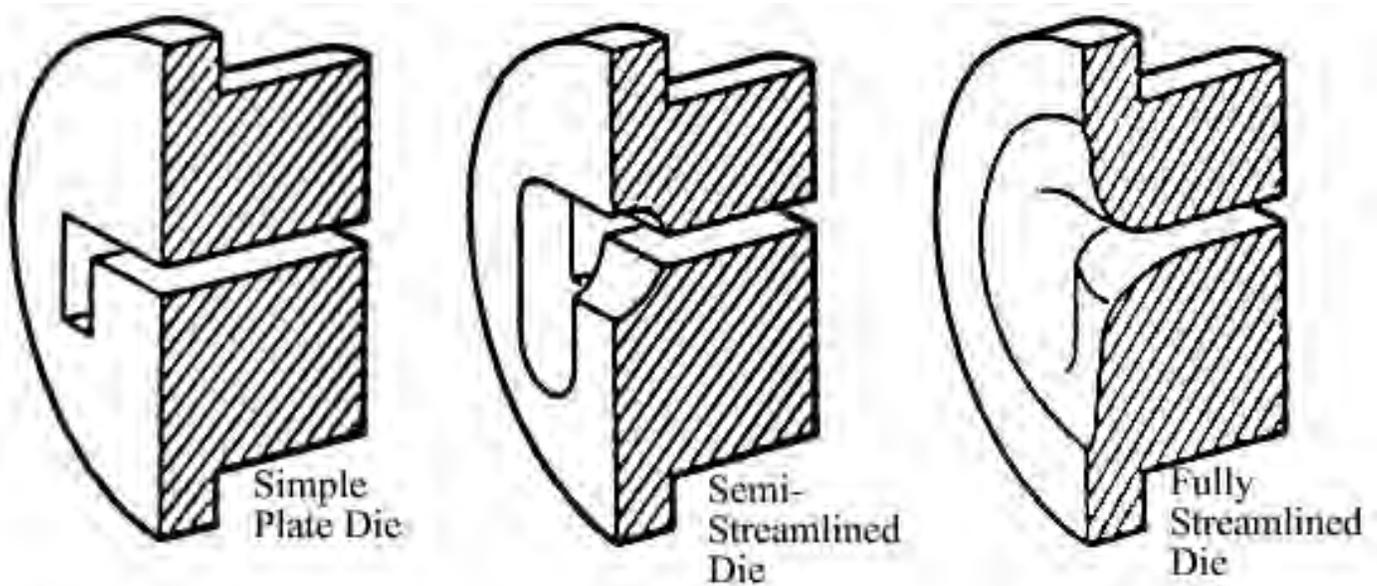


Figure 16

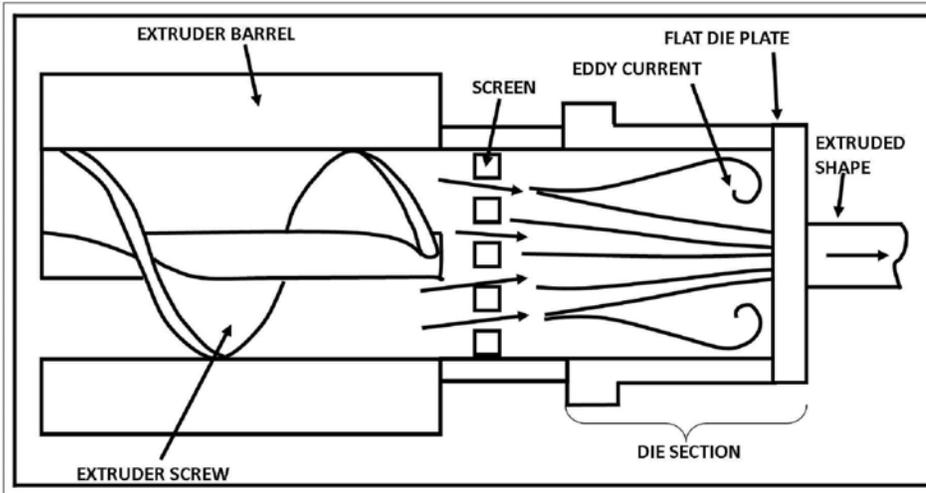


Figure 17

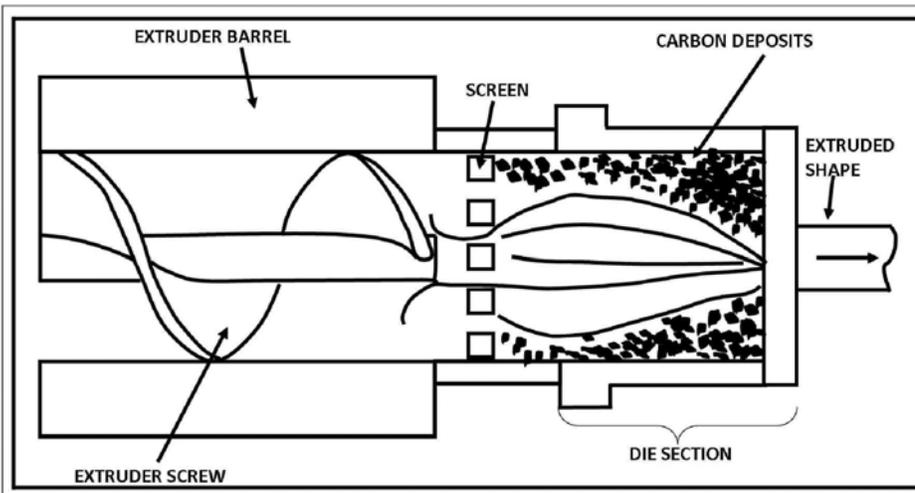


Figure 18

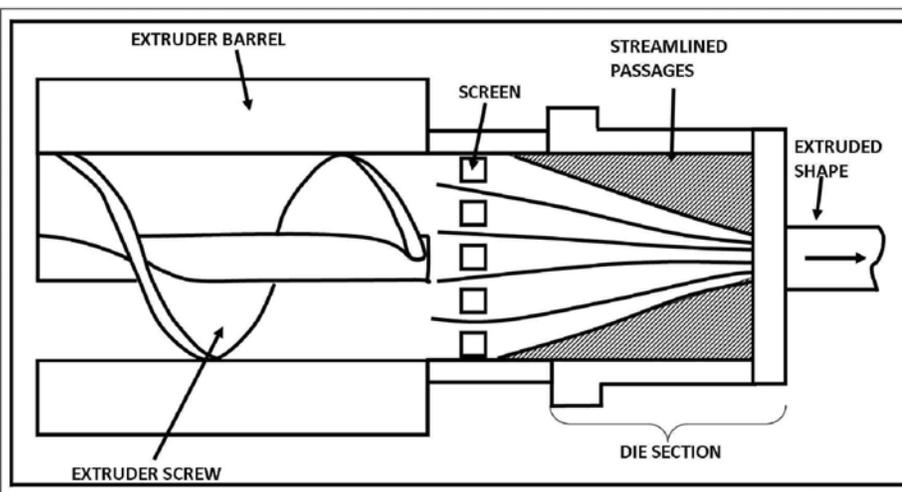


Figure 19

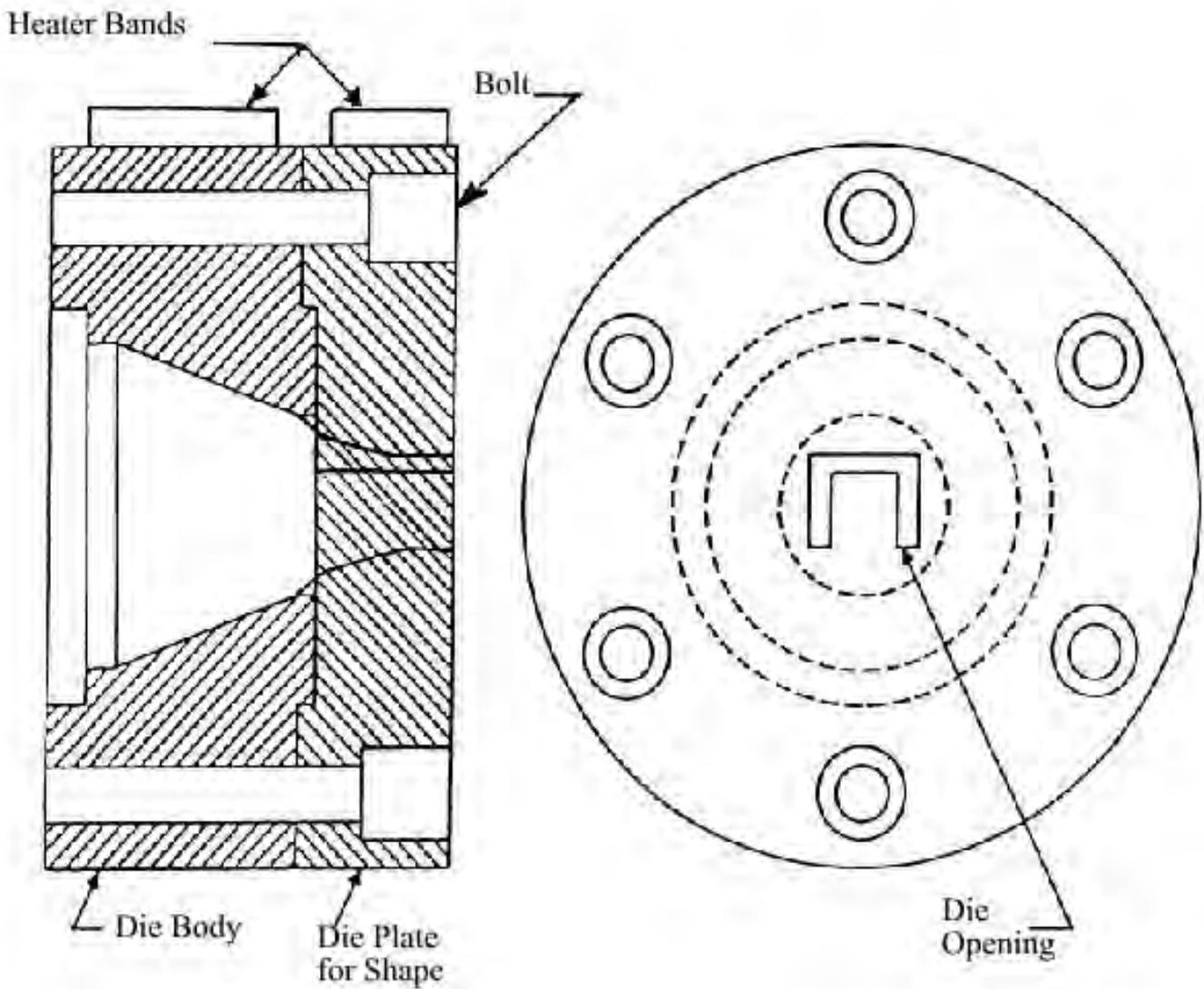


Figure 20

### Dies-General

It is essential that die land and mass be minimized for uniform expansion and fine cell structure. Pressure drops within the die land may allow cell formation while there is still shear stress and melt confinement, resulting in non-uniform expansion and surface defects. Under ideal no-land conditions there is no stress or confinement and the plastic will expand uniformly. It has been found in practice that equipment changes, other than short- to no-land dies, are usually unnecessary.

### Die Components

The die is responsible for shaping the PVC melt, which contains the blowing agent (BA), into the desired semi-finished cross-sectional product. Designing a die for this purpose corresponds closely to designing one for extruding unfoamed PVC. It is of particular importance that the cross section of the die decreases evenly to the required diameter at the die opening. This helps to maintain the melt pressure in the extruder above the gas pressure (vapor pressure) of the BA until just before the die opening. Since foaming of the melt within the tool leads to cell destruction (due to shear stress), the extrudate surface at the die land is kept as short as possible.

Proper design of the die lips is crucial for good foaming. The die should be designed so that expansion occurs just as the extrudate emerges from the die, not within it. Large land-dies cause foaming inside the die because the pressure of the gas/melt drops below the equilibrium pressure and enough gas precipitates out of the polymer to nucleate and grow a cellular structure. Foaming inside the die is detrimental in thin, monolayer films because it can result in poor surface appearance and decreased flowability and forming capabilities. Regions of retarded flow or “dead space” cause premature cell formation. This results in a poor or ruptured surface as the cells exit the die. The best outcome will result from a die that has a land-length to opening ratio no larger than 10:1. If the extrusion rate is very high, the ratio can be higher; at low extrusion rates a “no-land” die is recommended.

In general, we recommend short land-lengths to maintain high-pressure release rates. Low-pressure release rates reduce foaming considerably. For example, take two Champagne bottles that contain the same amount of liquid and gas and are the same temperature. If both bottles were vigorously shaken but one was uncorked slowly and the other was uncorked quickly, only the second one would produce foam. This is because the pressure release rate directly affects the rate at which foaming occurs. The gas bubbles exert a higher pressure and therefore, a higher release rate.

Pressure release rate can be affected by friction. As the resin laminar flows from the barrel into the die, molecules stick to the side of the die. As the die land is extended, there is more laminar flow, resulting in lower die exit pressure. Compare the molecules to logs flowing down a river. At the beginning of the river, all the logs flow in the same direction and at the same speed. But as they progress, some logs will become lodged along the riverbanks, and further still other logs will come into contact with these logs and their progress will be slowed. By the end of the river, hardly any logs flow, and they approach with minimal speed (pressure). This is similar to what takes place in long-land dies. It again illustrates why it is that the farther away from the barrel the resin is, the less pressure it exerts, which results in a lower pressure release rate and less foaming.

Since the pressure drops below the equilibrium level in every die, no matter how short the land is, the rate at which the cells form is important. Cells take time to nucleate and grow. This period is dependent on the gas/polymer systems, additives such as nucleators, and the percentage of maximum solubility for the system that is being used. If the cells start growth before the melt leaves the die, foaming in the die will occur. Three ways in which to inhibit this before modifying are as follows:

1. Increase rate. This will increase the melt pressure and move the melt through the die faster.
2. Lower the melt temperature. This increases solubility due to increased die pressure, and decreases the rate of cell nucleation and growth.
3. Lower the amount of blowing agent. This lowers the equilibrium level.

Increasing the rate usually increases shear heating, so lowering the melt temperature are counter-process changes. A middle ground will have to be found.

## Die Temperature

Die temperature control is important to maintain a consistent melt temperature throughout the die. This entails the proper use of cartridge heaters. They cannot be so close to the die lips as to cause temperature variations in the exiting melt. Many foam extruders use fluid channels in the die lip area and use outside heat and pump controls. This allows for more accurate temperature control of the die lip area.

The lower the foam density, the lower any variations may become. For angular shapes, it is important to control the temperature of the core and mandrel. This can be done by oil heat coil transfer systems, in which oil is circulated through the core and mandrel. This system is usually connected to the die and uses one zone for temperature control. Temperature is important because variations in the melt temperature cause variations in viscosity and hence, flowability. Temperature variations also cause differences in the degree of foaming; the higher the temperature, the more expansion is seen until the peak is reached and cell collapse occurs.

Annular, or pipe dies, generally perform better than straight dies, as uniform flow around the annular is more easily achieved than with straight slits. It is necessary to build up an adequate pressure in the extruder and die by appropriately configuring the die. In foamed film dies, the annular exit cross section narrows towards the outer die ring. Cooled die lips are even used for thick films so that the flow resistance is increased. The uniform, streamlined flow causes a rapid cell formation as the extrudate exits the die. Moreover, in blown film dies processing expandable materials, the die orifice is arranged at an angle (generally 45°) in order to avoid fold formation during the expansion. Spider legs, whose flow markings stand out more clearly on a foamed sheet than on a compact sheet, are also a problem. The number of spider legs is therefore kept small in such dies. There is one, possibly two, spider legs placed so that they are in the plane of cutting when the foamed sheet is slit open later. It is possible to achieve improvements in foamed polyethylene film extrusion by arranging positive displacement enlargements in the mandrel region behind the places where the melt passes through the mandrel support. A die land-length to opening ratio of 10:1 or less minimizes pressure drop in the land area.

Wire coating (or cross-head) dies are designed to have a low head volume, uniform pressure, and a streamlined flow path around the material being covered. Again, the land length-opening ratio should be 10:1 or less, with best results in some applications from a “no-land” die.

## Take-off Equipment

It is imperative that the take-off equipment be adequate to the task of achieving the desired extrudate. Normal take-off equipment may be used, but extra cooling is advantageous. The distance from the die lip to the take-off equipment is critical to maximize expansion that is consistent with the required surface appearance. Cellular sheet should be passed through chill rolls to polish the surface and give dimensional stability. Roll spacing should be adjusted to avoid over-compression of the sheet. Drawdown should be regulated to control sheet width. Cylindrical extrusions may be slit to obtain flat sheet. Foamed tubing and pipe extrusion can be made with conventional equipment; a vacuum-sizing tank and sleeve are normally used.

## Down Stream Equipment

Down stream equipment is an important part of extrusion foam manufacturing. It is important to cool and shape the material to the proper size. Cooling is important to stabilize the foam structure from shrinkage and post-blow, which is the slow expansion after initial deformation.

Sizing dies are common in many extruders such as for PVC and ABS water pipe. These dies can be vacuum active to pull the hardening PVC to a close tolerance size. They can also incorporate water-cooling to freeze the product at the same time. When foaming, it is important to use a larger sizing die to accommodate the increased cross-sectional area of the foam unless the foaming is directed inwards as with the Celuka process. The Celuka process uses an inner core that stops abruptly, providing the pressure drop for inward foam expansion.

Internal mandrels are often used for foam sheet applications. These mandrels are large cylinders that size the foam to the proper dimensions and cool the foam with water and air to prevent cell collapse from excessive heat build-up in the mandrel.

Aging and cooling processes are very important for many low-density foams. Since gas is diffusing out of the foam and air is diffusing in, often at different rates, and the gas inside the foam cells is cooling and reducing its vapor pressure, the potential for cell collapse and product shrinkage is created. Proper cooling and temperature control are essential to stabilize the foam and allow the internal cell pressure to reach equilibrium. Problems in cooling are often seen in thermoforming. When the roll has not stabilized, the application of heat causes distortion and shrinkage in the finished product.

The permeation of the gas is also dependent on the polymer structure. Crystalline polymers exhibit much greater resistance to gas diffusion because the crystalline structure is tightly packed in lamellae crystals. The gaseous molecule is too large to penetrate these crystals and therefore, cannot pass through. The interstitial space between the amorphous polymer molecules is large enough to allow the gas molecules to pass through. Gas diffusion is also dependent on the wall thickness of the cell.

### Cooling

Once the molten resin has exited the profile or sheet die, it must be cooled to fix its dimensions. Since the extruder's function is to transform and pump the resin and the puller/haul off is to maintain a constant pull to achieve dimensional stability in the profile, the now shaped melt must be sized and cooled to hold its physical dimensions and properties.

There are various ways to cool a profile to maintain dimensional stability. They are as follows:

1. Flood cooling
2. Vacuum cooling
3. Air cooling
4. Spray cooling

To cool and size the sheet, a three (3) roll polishing/cooling stand is needed.

### Flood Cooling

This is typically an open water tank in which a sizing fixture is mounted in the front and the extrudate passes through it. Cold water is circulated to prevent temperature stratification. This method would be used on simple non-hollow profiles; however, a sizer equipped for vacuum can be used.

### Vacuum Cooling

For large, hollow profiles, vacuum sizing is used to prevent the thicker cross section from collapsing, and to aid in sizing.

As the hot melt enters the vacuum sizer, it will begin to skin over, cool and finally “harden”. The vacuum applied to the tank internally lessens the water pressure enabling normal atmospheric pressure to “fill” the hollow internal openings preventing the profile from collapsing.

Once the profile is in the “sizer” and is being cooled while it is moving through, vacuum is applied to “pull” the extrudate outward to fix its dimensions. It is not uncommon to move the vacuum tank forward and increase the vacuum level to achieve dimensional stability.

Another common form of vacuum cooling is called “Dry Calibration”. This method utilizes a cored sizer, which has water cooling and vacuum ports. It is mounted on support rails in front of a water-cooling tank. At no time does water touch the profile, and since water acts as a lubricant it is necessary to plate the sizer for lubricity.

### **Air Cooling**

With some profiles forced air can be used to cool them. These profiles are usually thin wall, simple shapes.

Usually fans are located above and below the extrudate to evenly cool the profile. Sometimes a pair of cooling tunnels is used to intensify the airflow.

In this method “jigs” or “probes” are used to hold a profile in shape while it cools.

### **Spray Cooling**

This method can be used as primary cooling for simple profiles and as secondary cooling after a sizing fixture - in place of a flood cooling tank and vacuum tank.

Spray cooling utilizes evaporative cooling to pull heat out of the extrudate.

In each of these methods the length of the cooling tank is dependent on the line rate. The more cooling capacity the faster the extrudate can be made to run.

### **3 Roll Polishing/Cooling Rack**

Unlike the cooling of profiles, sheet products are sized and cooled by a different method. After it has exited the sheet die it is momentarily accumulated then sized by the polishing/cooling rollers.

The thickness of the sheet is controlled by two (2) factors; first; the gap of the die and second; the gap of the rolls (primarily the middle and bottom).

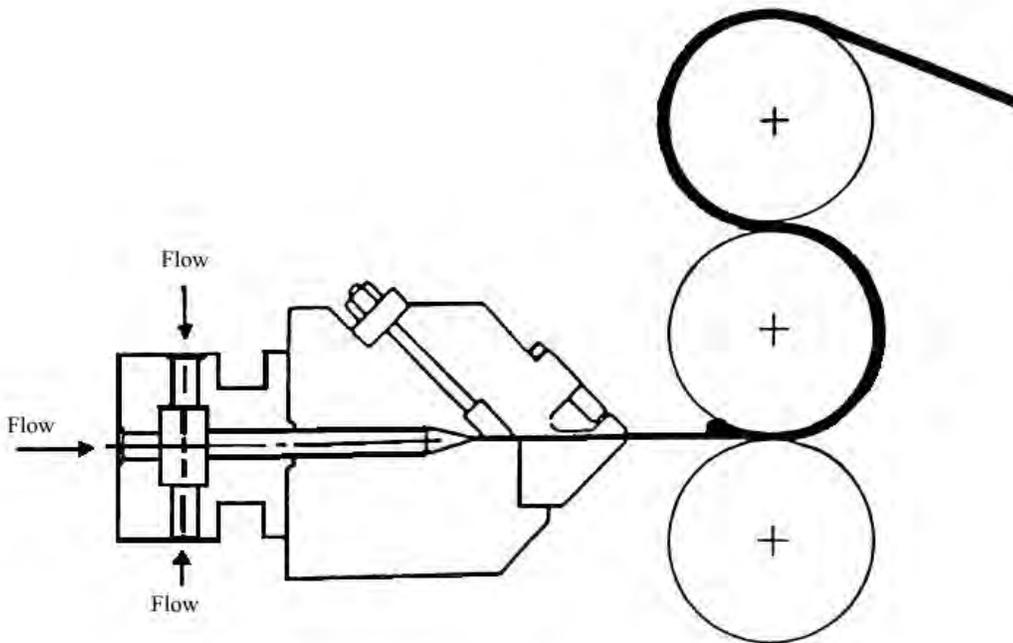


Figure 21

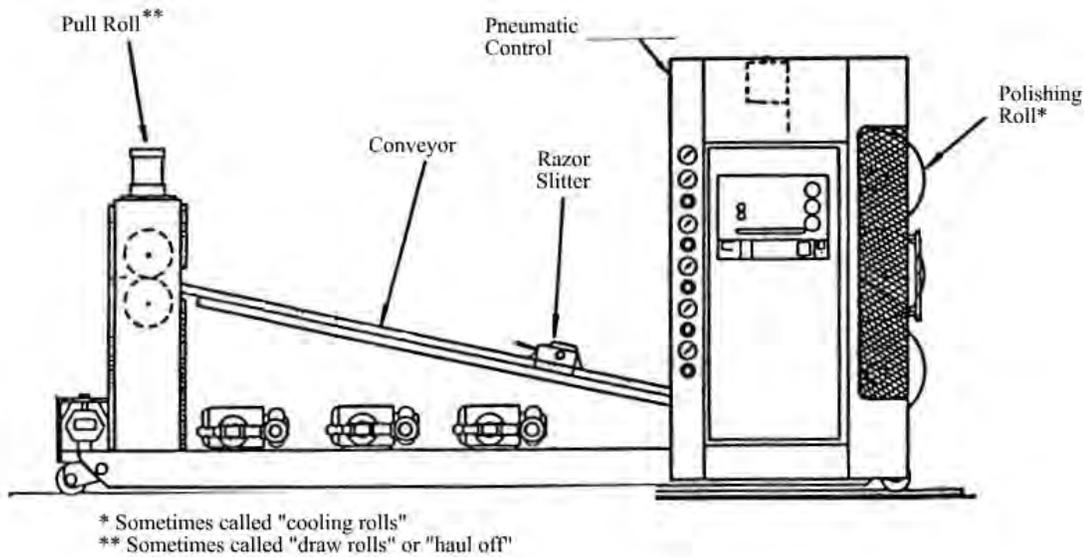


Figure 22

Although it is not always possible it would be very beneficial if a sheet producer was to have a different die for each size range of sheet being manufactured. This would minimize sheet stresses (orientation, shrinkage) and promote surface quality.

Each roll is independently controlled for speed (synchronized) and temperature. Uneven roll speed will shear the top and bottom of the sheet building in stresses, poor surface quality, affect physicals, etc. Independent temperature controls are necessary to cool the sheet gradually. Uneven temperature control can cause the sheet to stick to the rolls imparting “chatter” lines to the surface.

## Puller

As previously mentioned, an extruder will melt and pump a polymer, however it cannot push it through the sizer, cooling tank(s) and saw/cutter. The job of pulling the hot extrudate is performed by the puller/haul-off/caterpillar. Its sole purpose is to pull consistently and accurately control the parts dimensional stability.

Pullers can come in a variety of specifications; short or long belt contact length and width, endless belts or cleats, soft or hard, contoured or flat, AC/DC, etc. All are designed to meet exact production needs.

When selecting a puller for an application, certain production specifications must be checked; line speed, part size (cross section), resin, and output.

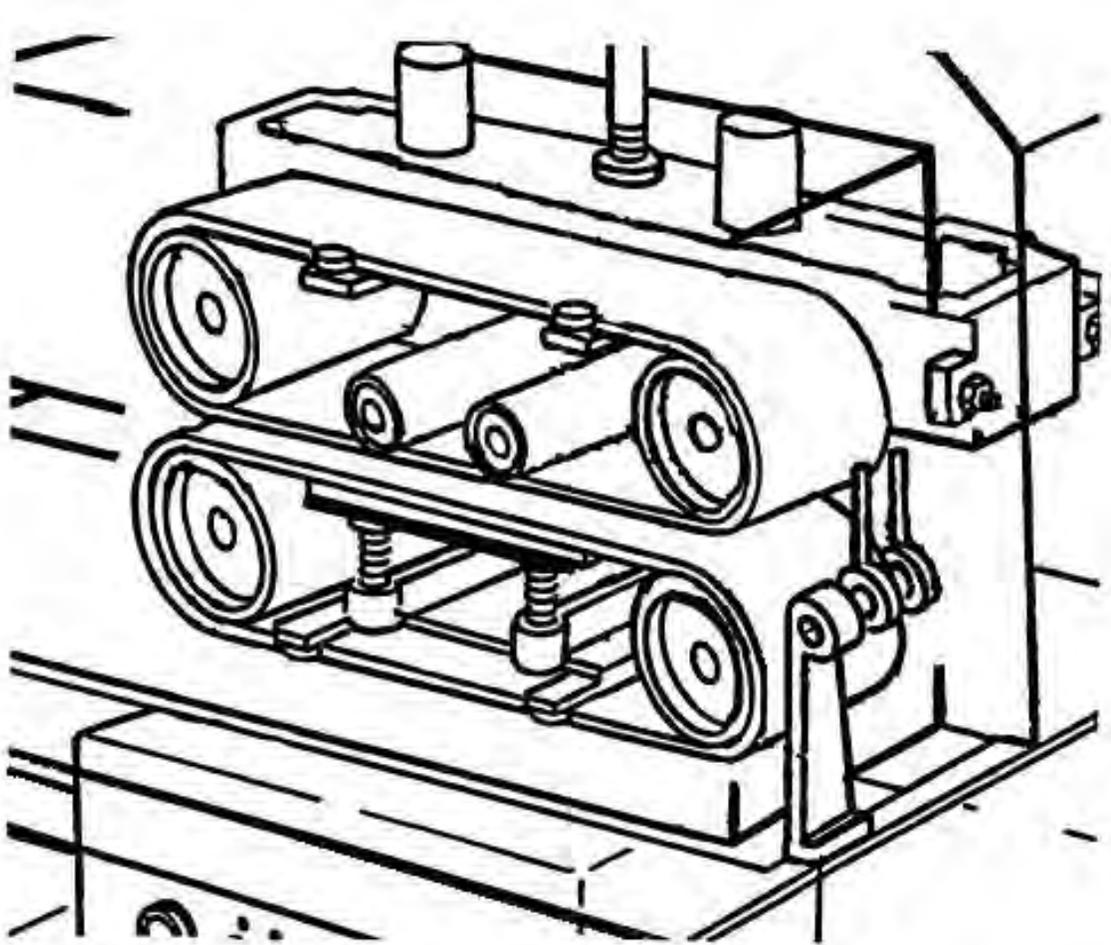


Figure 23

## Cutting/Sawing

Once a profile has been extruded and cooled it will be either cut to a specific length or lengths, which will be put in a secondary operation.

There are two methods of cutting profiles, saw and flying knife, and a shear for cutting sheet stock.

The cutters are divided into two methods of operation, continuous flywheel and clutch-cutter. In the operation of the flywheel cutter, the flywheel is continuously turning at a specified RPM with the cutting knife (blade) secured in a holder within the flywheel. Once the flywheel has rotated to the specified revolution count, the blade is extended, passes through the extrudate then retracts until the next full revolutions count.

The clutch cutter uses the principle of a knife blade in a fixed position waiting for an external triggering signal - photo cell, micro switch or digital encoder. Once the signal is received, the clutch is released and the blade makes one revolution through the passing extrudate then stops at a park position.

Regardless of which type of cutter is being used it is very important to select the proper knife blade for the part that is being cut. Knife blades come in a variety of styles and thickness to fit most cutting applications.

For thicker profiles a traveling saw is typically used. These are typically activated by photocell, digital encoder, micro-switch or dead stop. Once the saw has received the signal to cut, it will clamp the profile before and after the saw blade to prevent it from jumping to achieve a clean cut. Once clamped in place, the saw table will travel/move with the profile until the cut is complete at which point the clamps will release the profile and the table will return to its start position. Blade selection and cutting speed is important to get a smooth clean cut.

In the production of sheet stock, a shear is used because of the widths and thickness. The shear can be activated by various means but is usually activated by a digital encoder. When tripped, it will shear much like a pair of scissors, through a sheet.

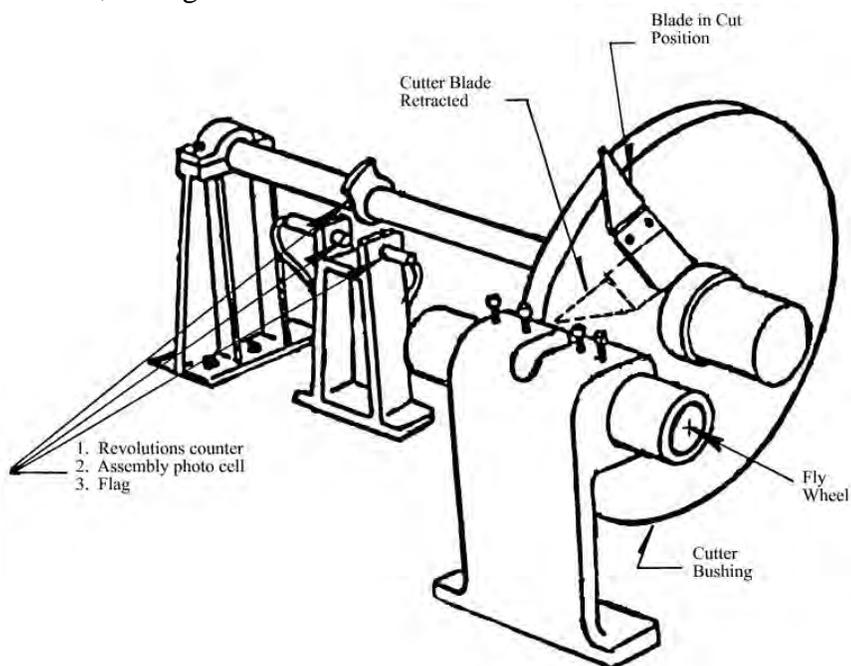


Figure 24

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## BENEFITS OF SAFOAM<sup>®</sup> IN EXTRUSION APPLICATIONS

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There are a number of important advantages to using **SAFOAM<sup>®</sup>** in extrusion, including material reduction, higher extrusion outputs, insulation properties, and increased part rigidity. For low-density foams, the addition of **SAFOAM<sup>®</sup>** can lower density, decrease cell size and reduce VOC emissions.

It is obvious that if a product is foamed, but has the same size and shape as a solid product, there must be less material in the solid product. Higher extrusion output is accomplished two ways:

1. Linear footage per hour increases, because the material foams in all directions, including the machine direction. If the solid product runs at 1,000 ft/hr and 30% foaming is attained, then about 10% foam expansion in the machine direction increases the rate to 1,100 ft/hr.
2. Increased output also comes from the increase in flow. CO<sub>2</sub> lowers the viscosity of the polymer melt, which increases the flow rate with all other variables constant. (All of these benefits may not be seen if the process parameters have to be drastically changed in order to support a cellular structure.)

Thermal properties are increased with a cellular structure because the cells act as barriers to conductive heat flow. Part rigidity is increased for products that have the same amount of material and are allowed to grow in size, i.e. using the same die. The increase in thickness increases the flexural strength of most materials. By doubling the thickness, the flexural strength is increased eight times for materials of the same flexural modulus. Foaming, in general, initially reduces the physical properties of thermoplastic materials, but the strength to weight benefit is quickly seen as density is decreased.

Compared to other foaming agents, the addition of 0.5% **SAFOAM<sup>®</sup>** in a low density foamed product increases nucleation because of the high vapor pressure of CO<sub>2</sub>. This creates a greater number of smaller cells. The smaller cells have a higher percentage of closed cells vs. open cell, helping to reduce emissions of the PBA. Moreover, a lower amount of PBA is used when CO<sub>2</sub> is used because CO<sub>2</sub> provides much of the blowing force.

### Extrusion Processing

Processing of quality-foamed extrudate requires the proper amount of foaming agent, acceptable pressure drop and pressure drop rate, melt temperature in the acceptable range, and proper tooling. Each of these parameters can be varied to some degree to achieve the desired results. When replacing an exothermic blowing agent, the only parameter change usually warranted is the increase in barrel temperature to raise the melt temperature. Since an exothermic foaming agent supplies heat to the polymer melt upon decomposition, and an endothermic foaming agent removes heat, this must be compensated for by adding more heat into the melt.

Most extruders can process a foamed extrudate to some degree. The lower the density desired, the more demand will be placed on the machine's capabilities. The extruder must be able to decompose any CBA used, mix the gas and polymer, cool the melt to the desired temperature and provide enough pressure to the die lips to achieve the desired foam structure. The machine output should correspond to the die size and shape. A small 1½" extruder should not be used to foam a 4' x 1" board stock, but a 4½" x 6" tandem could make a single strand of ½" foam rod.

Cooling capacity is more critical in lower density foams. This can be accomplished by way of secondary screws, heat exchangers, or very long l/d (length divided by diameter) screws. Along with the importance of cooling is melt temperature stability. The melt temperature throughout the cross-section of the melt needs to be uniform. Variations can come from heat and cool cycles in the temperature controllers, or pulsing in the screw. These need to be minimized through good-quality temperature controllers and a properly designed screw.

### Setting Extruder Equipment for SAFOAM<sup>®</sup> Implementation

When foaming for the first time, a step-by-step procedure can be followed to achieve good results. Even though each material and gas composition and each extruder will require different process parameter settings, the principles are the same. The solution of gas and polymer must exit the die with a sufficient pressure and pressure drop rate at the right temperature. The first parameter to adjust is the melt temperature. A ballpark figure can be found in the viscosity vs. temperature curves for that material. If not available, close observation should be sufficient. While running the extruder at half speed with three quarters of the approximate level of blowing agent needed, adjust the melt temperature down until the extruder is at about 90% of maximum amperage. The extrudate should be very thick and viscous. At this point, slowly raise the melt temperature. As the melt temperature increases, the viscosity should decrease. At some point the extrudate will start to expand and foam. Just beyond the optimum melt point, the extrudate will grow then begin to collapse. This will indicate that the melt temperature is now too hot. Reduce the melt temperature and measure it with a melt temperature probe. This value will remain about the same for this material. Changes in output, die configuration and blowing agent level will require adjustment in melt temperature.

Now begin increasing the screw RPM. Generally, the melt temperature will increase with RPM. It will be necessary to maintain the melt temperature by reducing the barrel and nozzle temperature. A level may be reached where the extruder cannot cool the melt sufficiently at the higher output rates. Without additional cooling capacity, this will be the limit on output. As with solid material, there is a limit to the flow rate of the material through to die. Melt fracture will occur in solid and foamed material. While increasing the rate, adjust the melt temperature to achieve the desired foam structure. If additional expansion and a lower density are desired, increase the percentage of blowing agent.

### Measuring Performance Improvements of SAFOAM<sup>®</sup> in Extrusion Applications

There are a number of approaches to analytically measure performance benefits of applying SAFOAM<sup>®</sup> to the foam extrusion process. The primary benefits are in the areas of material weight savings, direct gas savings, improved extrusion rates and reduced scrap and rework. Table 3 is a detailed cost model providing an approach to objectively measuring the costs and benefits of SAFOAM<sup>®</sup> technology. Depending on equipment and processing objectives, individual results will vary. However, in a number of real applications, savings in the following areas have been realized:

Improvement Area	Savings Range
Material Weight Savings	15% to 45% over solid extruded materials
Improved Extrusion Rates	Up to 20% increase in output per hour
Reduced Scrap and Rework	Up to 9% reduction in rework costs

One actual measured example is in the production of coextruded pipe. Using a standard of production costs per linear foot of finished pipe, actual cost savings experienced were almost \$0.73 cents per lineal foot of foam vs. solid pipe.

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## EXTRUSION FOAMING

Foam formation is the critical step in the process of foam extrusion, since it depends on the viscosity and elasticity of the plastic melt, the vapor pressure of the blowing agent, and the mutual effects of the plastic melt and the BA on each other (solubility and permeability).

At the moment the molten plastic leaves the extruder, the BA is dissolved as gas in the melt. Therefore, it is immaterial whether the BA was originally a CBA that decomposed to release gas at a certain temperature, or a PBA, and it is not important how the BA was introduced into the melt. The drop in pressure at the exit from the extruder nozzle causes a supersaturation of the gas dissolved in the melt. The two phases, gas and melt, separate and the gas immediately forms innumerable bubbles, which are the nuclei of the foam cells. These bubbles grow until the gas pressure inside the bubbles and the surface tension of the bubble walls are in equilibrium, taking into account the viscosity of the plastic melt (which is cooling as a result of expansion and heat loss to the environment) and the concentration of the gas still in solution. The foam must harden and solidify as soon as this equilibrium is reached, or the cells will collapse. The foam structure is stabilized by rapid and intensive cooling.

The condition of the surface of the extruded article is already determined, even at the beginning of the cooling and hardening process. If the expansion of the semi-finished product is suppressed directly upon its emergence from the extruder by intensive cooling of the surface, the article will form a hard skin or membrane. Depending on the intensity of the cooling, this hard skin can be a layer that is less foamed than the interior material, or it can be a completely compact, unfoamed layer. If the plastic is allowed to foam freely upon its emergence from the extruder, the surface will be relatively soft. This freely foamed, soft surface can be smoothed by contact with a cool calibrating unit.

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## EXTRUSION PROCESSES

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### Expanded Sheet

Expanded sheet can be thermoformed to give a product the advantages of resilience, opacity, insulation properties, and low cost. It can either be:

- a. expanded in the extrusion process, or
- b. expanded during the forming process.

The preferred method is to expand the sheet during extrusion, followed by the forming step.

### Blow-molding

Blow molding is a two-stage process. A hot tube or parison is extruded and then molded by inflation within a mold. The general principles for successful extrusion apply to the parison. A parison can be made in one of two ways:

- a. continuous extrusion (similar to pipe extrusion) or
- b. intermittent extrusion

In method b, the melt must be kept under pressure to prevent premature cell formation, resulting in poor or rough surface. As soon as the parison exits the die, expansion and cell formation occur. The die and pin diameter must be adjusted to compensate for expansion. The die diameter must be reduced and the pin diameter increased. Conventional molds are employed (i.e. stationary, reciprocating, or rotary). Since the hot strength of the melt is lower, mold release may be required on the hot knife or wire to obtain a clean cut-off. The blow-pressure may have to be reduced to avoid wall rupture.

### Wire and Cable

Foaming of polyethylene enhances electrical properties. It is extruded on to wire conductors using cross-head dies. The wire temperature is very important; if it is too low, the foam density will be too high; if it is too high, large cells may form around it. Rapid cooling of the extrudate will prevent sagging, particularly in thick-wall insulation.

## EXTRUSION PROCESS PROFILES

### Celuka Process (Integral or Inward Foaming)

In this process the semi-finished product is vigorously cooled over its entire surface immediately upon its emergence from the extruder. Simultaneous shaping prevents enlargement of the cross section (Figure 59). The total area of the die orifice is only a fraction of the total cross section area of the desired final profile. Foaming is restricted to the core of the extrudate, with foam filling the cavity left by a coaxial torpedo or pin within the extruder and then entering a cooled shaper adjacent to the die. In the shaper, the outer surface of the extrudate is quickly cooled as it comes in contact with the metal surface to form a solid plastic skin. At the same time, expansion of the thermoplastic foam takes place inwardly, forming a uniform cellular core covered with a solid plastic skin. In contrast to the free-foaming process, discussed next, there is no longitudinal dimensional change; total expansion is two-dimensional. Integral foaming yields semi-finished articles with a solid, hard skin. The thickness of the dense surface skin can range from 0.1 to 1mm, depending on the intensity of cooling. This integral foam process is known as the *Celuka Process*. It can be used to produce pieces of almost any desired cross section, as well as sheet and tubing, as long as the wall thickness is over 6mm.

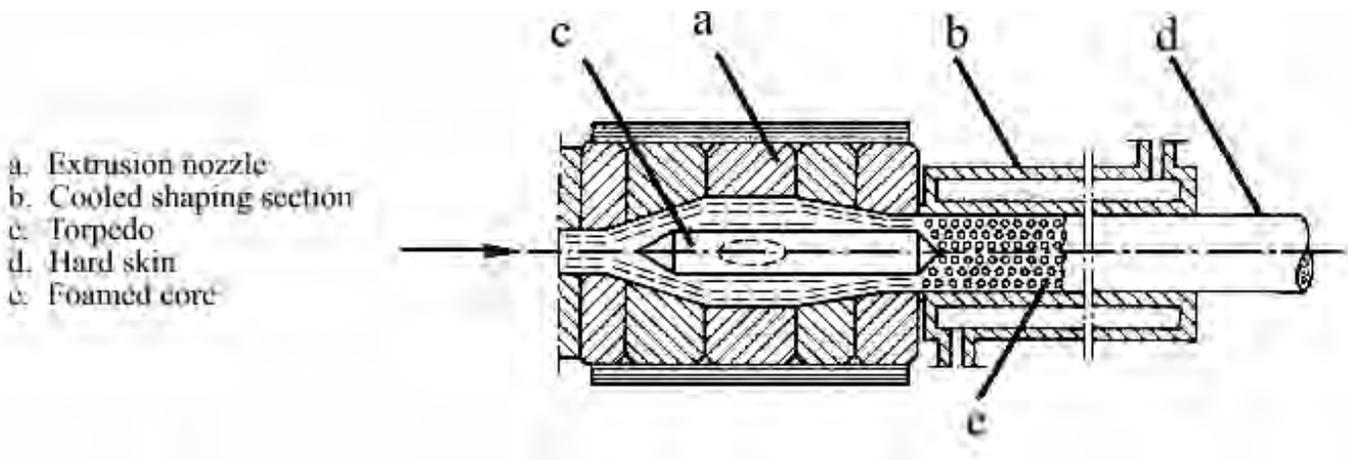


Figure 25

Chief advantages of Integral Foaming are as follows:

- thick skin of unexpanded thermoplastic
- surface appearance and properties
- skin reinforcing effect
- foam insulation and energy absorbing properties
- dimension and density control
- one-step manufacture of complex shapes
- good properties at lower densities

### Free-Foaming

In this process the melt expands freely upon its emergence from the extruder. Foaming coincides with swelling and elastic recovery of the extrudate. The extrudate therefore increases in cross section and decreases in length, and the take-off speed is lower than the extrusion velocity if the extrudate is not drawn down. In free-foaming, cells form in the entire cross section of the semi-finished product, but because the extrudate is cooled, cell growth on the surface is limited. The result is an integral foam with relatively high density near the surface and lower density in the core. As the semi-finished product passes through the shaping section, its surface becomes smoothed.

The manufacturer is limited to relatively simple shapes (including hollow pieces), sheet, and tubing, all with wall thicknesses in the range of 2-6mm, from rigid PVC.

Advantages include ease of processing, no special equipment, and low cost. However, lack of sophistication, foam's high water absorption, and limits on the pieces' thickness are specific drawbacks of this process.

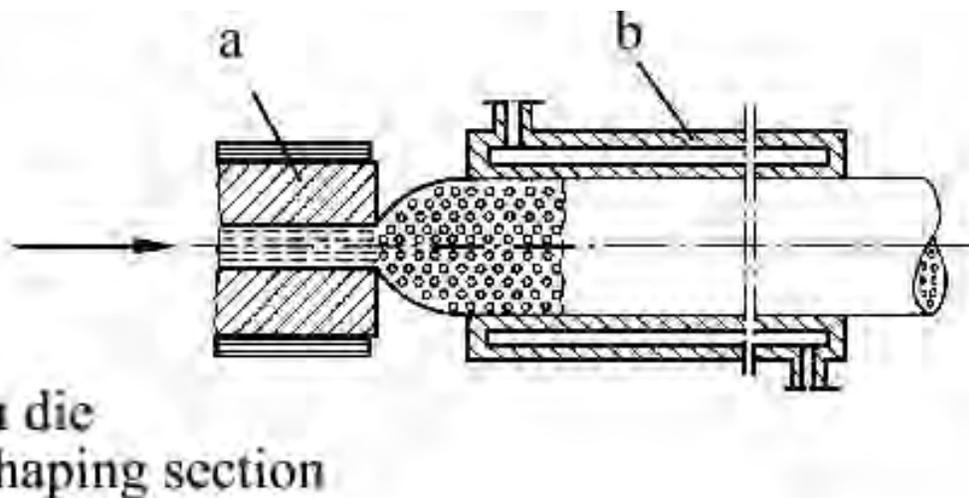


Figure 26

### Co-Extrusion

Material produced by this process consists of a foam core contained within a solid skin. Essentially, this technique involves the simultaneous extrusion of a foaming melt and a solid PVC cap stock. This technique results in a clean, glossy surface, and it furnishes the manufacturer with a high level of control over the nature of the finished product.

Benefits of the process include an excellent finish with superb weatherability. The co-extruded product also demonstrates exceptional mechanical properties, and the manufacturer has the opportunity to mix and match different foams and cap stocks. On the other hand, co-extrusion demands a large investment in equipment, (two extruders), and space.

## GUIDELINES FOR SUCCESSFUL FOAM EXTRUSION

1. Provide good mixing in the extruder.
2. Ensure a high enough temperature in the extruder to initiate **SAFOAM®** decomposition.
3. Ensure that the pressure on the melt in the barrel is sufficient to prevent premature expansion. Increased screw speed helps with this and results in higher extrusion rates.
4. Ensure that the screw is not vented (or plug the vent).
5. Avoid ‘dead space’ and pressure drop in the die or the flow of the melt will fluctuate (with gas loss and loss of control).
6. Keep die temperature as low as possible to promote a smooth skin.
7. Keep die “land” length to a minimum. A die land-length to opening ratio of 10:1 or less is preferable. Sometimes very high viscosity resins may need a larger land. Minimum land-length ensures higher pressures on the extrudate, preventing premature cell formation. A sharp pressure drop at the die lip promotes better, more uniform cell structures.

Typical Processing Conditions					
ZONES	PP °F (°C)	ABS °F (°C)	PS °F (°C)	HDPE °F (°C)	PVC (Rigid) °F (°C)
Rear	360 (182)	360 (182)	340 (171)	340 (171)	350 (177)
Middle	380 (193)	380 (193)	360 (182)	360 (182)	360 (182)
Middle	400 (204)	400 (204)	380 (193)	380 (193)	370 (188)
Front	420 (215)	420 (215)	400 (204)	400 (204)	360 (182)
Die	400 (204)	400 (204)	380 (193)	380 (193)	350 (177)

## HEAT TRANSFER MODEL

The heat transfer model was developed by Mark Schuetz and Leon Glicksman at the Massachusetts Institute of Technology. Schuetz has shown that the total thermal conductivity of a foam is a combination of three contributions: conduction through the polymer, conduction through the cell gases, and thermal radiation. Convection as a heat transfer mechanism in closed cell foam insulation is negligible.

### Conduction

Microscopic analysis of the cell structure in a polyurethane foam shows that the cell faces are composed of thin membranes which are bounded on all sides by thick elements termed ‘struts’. Each strut forms at the intersection of three cell walls and results from drainage during foam formation. The thin cell membranes and relatively thick struts comprise the two structural elements in the foam geometry. Conduction through the polymer has been analyzed by considering the distribution of polymer material between cell walls and struts and by evaluating conduction in the actual cellular structure through upper and lower limiting models.

By staggering the cells, the effect of the tortuous path of conduction can be determined. Heat flow through randomly oriented planes and randomly oriented sticks gave the same analytical results as the preceding analysis. This suggests that the conduction term is essentially independent of cell geometry. For any given cellular geometry, the cell walls will be statistically oriented for greater heat flow as compared to the struts.

The cell gas conductivity,  $k_g$ , can be combined with the polymer conduction term when the cell gas composition is uniform within the foam cross section. The case when the cell gas composition varies across the foam thickness will be discussed later in the manual. The upper and lower limits to the conduction term can now be summarized. The upper limit of the conduction model is given by:

$$k_{s+g} = k_g + \left( \frac{2}{3} - \frac{f_s}{3} \right) (1 - \delta) k_s$$

Figure 27.

Three parameters must be experimentally obtained from the foam to evaluate the polymer conduction term in Figure 27. The polymer distribution parameter,  $f_s$ , is the fraction of the polymer material contained in the struts of the foam. An experimental technique to calculate this parameter is presented in the Gas Diffusion Model section of this guide. Note that the coefficient of the polymer conduction term reduces to the two limiting results when  $f_s$  is zero (no struts) and  $f_s$  is unity (no walls). The porosity,  $\delta$ , is the fraction of the total foam volume which is occupied by the cell gases and is given by the following,

$$\delta = \frac{\rho_s - \rho_a - \rho_f}{\rho_s - \rho_g}$$

Figure 28.

where  $\rho_s$ ,  $\rho_a$ ,  $\rho_f$ , and  $\rho_g$  are the densities of the polymer, air, foam and cell gases, respectively. The polymer conductivity,  $k_s$ , must also be determined. Mark Sinofsky developed a transient hot wire thermal conductivity testing technique at the Massachusetts Institute of Technology to measure the thermal conductivities of foam polymers. The majority of Sinofsky's data is on urethane foam polymers but isocyanate, polystyrene and phenolic polymers have also been tested. The lower limit of the conduction model is given by:

$$k_{s+g} = k_g + 0.8 \left( \frac{2}{3} - \frac{f_s}{3} \right) (1 - \delta) k_s$$

Figure 29.

The difference of 20 percent in the solid conduction term between the two limiting models results from a consideration of the tortuosity of the conduction path. The uncertainty between the two limiting models amounts to less than five percent of the overall foam conductivity.

### Thermal Radiation

The approach to the modeling of thermal radiation in the past has been to assume that the cell walls in foam insulation are opaque to thermal radiation.

Thermal radiation in foam insulation involves radiant transport in non-gray, emitting, absorbing and anisotropically scattering media. For commercially available foams, it has been shown that the attenuation of thermal radiation is primarily absorption dominated and that scattering can be treated as isotropic. These results simplify the experimental means of determining the contribution due to thermal radiation heat transfer and yet only introduce a margin of error of 10 to 15 percent in the radiation heat flux term.

The experimental approach has been to directly measure the attenuation of thermal radiation in foams by placing thin foam slices in an infrared spectrophotometer and measuring the percentage transmission of radiation through each sample. Figure 29 shows a typical spectrograph for a thin slice of polyurethane foam. The transmission spectrum is approximately uniform so that an average transmission value can be determined for the sample thickness. Additional tests are conducted on other foam samples covering a range of thicknesses. When the percentage transmission values are plotted versus sample thickness on a semi-log plot, the data forms a straight line.

Figure 30 shows a plot of the average percentage transmission values obtained experimentally versus sample thickness. The data shows that thermal radiation is exponentially attenuate in the foam as the foam thickness increases to larger and larger values. As expected, the percentage transmission extrapolates to 100 percent at zero sample thickness. The slope of the line is termed the foam's extinction coefficient,  $K$ , and is the key parameter required to quantify thermal radiation heat transfer in the foam.

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## HEAT TRANSFER MODEL

The thermal radiation contribution including the foam's extinction coefficient is combined with the conduction heat transfer contributions to obtain an expression for the overall foam thermal conductivity,

$$k_{eff} = k_g + \left( \frac{2}{3} - \frac{f_s}{3} \right) (1 - \delta) k_s + \frac{16\sigma T_m^3}{3K}$$

Figure 30.

where  $T_m$  is the mean temperature of the foam and  $\sigma$  is the Stefan-Boltzmann constant. The contributions due to conduction through the polymer and thermal radiation will remain essentially constant during foam aging. The cell gas conduction contribution will change as atmospheric gases diffuse into the cells of the foam and Freon gas diffuses out of the foam. A gas diffusion model is required to predict the changes in cell gas composition that occur during foam aging. The cell gas composition, in turn, determines the cell gas conduction contribution in the heat transfer model.

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## GAS DIFFUSION MODEL

The gas diffusion model was developed by Douglas W. Reitz and Leon Glicksman at the Massachusetts Institute of Technology.

An overview of the aging process in closed cell foam insulation is shown in Figure 31. A freshly-made foam contains primarily Freon gas with small concentrations of carbon dioxide, oxygen and nitrogen. Any carbon dioxide formed during foam formation rapidly diffuses out of the foam. Oxygen and nitrogen diffuse into the cells of the foam over time while Freon gas simultaneously diffuses out of the foam. The high molecular weight of Freon causes it to diffuse much more slowly through the foam structure than oxygen or nitrogen. This overall diffusion process leads to a decline in the R-value of the foam during its lifetime. The use of a facing at the surface of the foam board may reduce the rate at which the foam ages.

Cuddihy and Moacanin showed that foam insulation can be treated as a homogeneous media that obeys Fick's law of diffusion. Commercially available foams will satisfy the requirement of homogeneity unless the foam contains large voids, collapsed cells or other defects that disturb the local gas diffusion process. The one-dimensional form of Fick's law that is applicable to diffusion in foams is given by,

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{D} \frac{\partial p}{\partial \tau}$$

Figure 31.

where  $p$  is the partial pressure of the gas in the foam board and  $D$  is the diffusion coefficient of the gas in the foam. The diffusion coefficient determines the transport rate of the gas through the foam medium and must be obtained for each diffusion gas. Two major factors must be considered in developing an expression for the diffusion coefficient: 1) the effect of the foam's cellular structure on the gas diffusion rate, and 2) the mechanism of gas transport through the polymer membranes that separate adjacent cells in the foam structure. The effects of cellular geometry on the diffusion rate will be discussed first.

## Foam Cell Geometry

The cell morphology in foam insulation was quantitatively analyzed by preparing two-dimensional, planar views of the cell structure. The view of the cell structure shown in Figure 32 was obtained by treating a foam with an embedding resin. A foam sample was placed in an initially liquid, low viscosity resin that filled in the open cells at the surface of the sample. The resin-treated sample was cured in an oven and then cut into thin sections using a microtome. The resin can be seen filling in the center of the cells normally occupied by cell gases.

The two-dimensional sections provide a means of determining the distribution of polymer material between cell walls and struts within a foam. The fraction of polymer material contained in the cell walls is of primary importance since the struts play essentially no role in the gas diffusion process. The polymer distribution parameter is determined by measuring the cell wall thickness and

surface area to volume ratio of a foam using the two-dimensional sections. The cell wall thickness can be measured at high magnification using a scanning electron microscope. The thin polymer membranes are subject to swelling as a result of interaction between the embedding resin and the polymer material. The extent of the polymer-resin interaction was investigated by measuring the thickness of a polyurethane film before and after use of the resin. The measurements revealed a swelling of the polymer material between 34 to 69 percent due to the resin. Thus, the measurements should only be used as an upper limit estimate to the actual cell wall thickness in the foams.

The surface area to volume ratio of a foam is also measured from the sections. A test line is drawn across a section photograph and the number of intersections between the test line and foam cell walls are counted. The sample's surface area to volume ratio,  $S_V$ , is expressed in terms of the parameter,  $N_L$  (number of intersections/test line length). In general,

$$S_V = 2N_L$$

Figure 32.

and is valid when uniformity of sampling is attained and the samples are representative of the structure. By combining the surface area to volume ratio with the cell wall thickness,  $t$ , the fraction of polymer contained in the cell walls can be determined,

$$f_w = \frac{(S_V)(t)}{(1 - \delta)}$$

Figure 33.

where  $(1 - \delta)$  is the fraction of the foam volume occupied by polymer material (struts plus cell walls). Measurements of polymer distribution in five polyurethane foams showed that the cell walls contained only 10 to 20 percent ( $f_w = 0.10$  to  $0.20$ ) of the polymer material in a foam. Thus, most of the polymer material is not retained in the cell walls of a foam where it can be utilized in reducing gas diffusion into the foam cells.

The diffusion of a gas through the cell structure shown in Figure 32, can be modeled by assuming that the cell walls are spaced, on average, one cell dimension apart. The idealized cubical cell structure shown in Figure 33 can then be used as a first approximation to the actual cell structure in Figure 32. The assumptions used in conjunction with the cell geometry in Figure 33 are:

1. uniform cell wall thickness
2. resistance to diffusion only in cell walls
3. one-dimensional gas flow
4. no pinholes or cracks in cell walls

Each cell wall can be considered a resistance to diffusion with a diffusion coefficient,  $D_s$ , that determines the transport rate of a gas through the cell wall. Each cell has an average cell dimension,  $d$ , and each cell wall has a uniform thickness,  $t$ . Summing over all resistances and equating to an effective resistance, the effective diffusion coefficient,  $D_{eff}$ , that determines the transport rate of a gas through the foam's cellular structure is given by,

$$D_{eff} = \frac{t+d}{t} D_s \cong \frac{d}{t} D_s$$

Figure 34.

since  $d > t$ . In addition to the cell geometry parameters, the effective diffusion coefficient is directly proportional to the cell-to-cell gas transport rate, defined by the polymer diffusion coefficient,  $D_s$ . This transport coefficient must be considered before continuing with the development of the model.

## Gas Transport Process

A side view of a cell wall with thickness,  $t$ , separating two adjacent cells is shown in Figure 34. The gas transport process through the membrane is defined as having three stages. In the first stage, the gas, at concentration  $c_1$  or pressure  $p_1$  (the two are related by the ideal gas law), is absorbed on to the surface of the membrane. The dissolved gas then diffuses along a concentration gradient through the membrane to the opposite surface in the second stage.

Finally, the dissolved gas comes out of solution to a lower pressure  $p_2$  or gas concentration  $c_2$ . The absorption step at the surface of the membrane is controlled by the solubility of the gas in the polymer. In general, Henry's law is obeyed so that the gas pressure at the membrane surface is linearly proportional to the gas concentration within the membrane. The three-step process is termed permeation and is driven by the difference in the gas partial pressure across the membrane. The defining equation for the permeability at standard conditions (**STP**: 273 K, 76 cm Hg) is,

$$Pe = \frac{(V_{STP})(t)}{(p_1 - p_2)(A)}$$

Figure 35.

where  $V_{STP}$  is the volume flow rate of gas at **STP** passing through a membrane of thickness  $t$  and area  $A$  under a differential gas pressure  $(p_1 - p_2)$ . Each gas is not influenced by the presence of other permeating gases although water vapor and Freon may have some plasticizing effects on the permeation of the other gases.

A diffusion coefficient is defined in terms of the membrane permeability which accounts for all three steps of the transport process through the cell membrane. The diffusion coefficient is based on the difference in the gas phase concentrations ( $C_1-C_2$ ) and assumes the following,

1. Henry's law is obeyed by the diffusion gas.
2. The ideal gas law applies to the diffusing gas.
3. Any interaction between the gas and the polymer does not significantly alter the permeation process outlined above.

Using these assumptions in combination with the definition of the permeability in Figure 35, the diffusion coefficient  $D_s$  is given by,

$$D_s = \left( P_{STP} \frac{T}{T_{STP}} \right) P e_s$$

Figure 36.

where  $P_{STP}$  and  $T_{STP}$  are the gas pressure and temperature at **STP**, respectively and  $T$  is the test temperature. The permeability of each diffusing gas in the foam polymer must be evaluated for use in the gas diffusion model. Permeability data has been obtained using both the variable volume permeability testing method and the variable pressure permeability testing method (see ASTM D1434-75 for a discussion of the testing methods). Test films were prepared by combining the foam components (excluding the blowing agent) and casting them into thin films (one to three mils thick). The films were post-cured in an oven. Note that catalyst levels had to be reduced to avoid bubble formation.

The results of the cell-to-cell gas transport analysis can now be combined with the gas diffusion model. Before summarizing the model, it is important to note that the cell shape in foams is more accurately represented by a pentagonal dodecahedron or a truncated octahedron than a simple cubical cell. The surface area to volume ratios of these cell shapes can be related to the average cell dimension,  $d$ , in the foam's cell structure. The pentagonal dodecahedron and truncated octahedron have surface area to volume ratios of 3.46/d and 3.55/d, respectively, when in an aggregate of cells each shares half of its surface area with adjacent cells surrounding it. Using the pentagonal dodecahedron cell shape and the results from Figure 36, the effective diffusion coefficient defined Figure 34 becomes:

$$D_{eff} = \frac{3.46}{(S_V)(t)} \left( P_{STP} \frac{T}{T_{STP}} \right) P e$$

Figure 37.

Combining this result with Figure 33 shows the dependence of  $D_{eff}$  on the fraction of polymer in the cell walls  $f_w$  and foam density:

$$D_{eff} = \frac{3.46(\rho_s - \rho_g)}{f_w(\rho_f - \rho_g + \rho_a)} \left( P_{STP} \frac{T}{T_{STP}} \right) P e_s$$

Figure 38.

These equations may be applied to the gas diffusion process under any high temperature aging conditions (i.e., 60°C) by simply substituting the appropriate high temperature permeabilities and the permeability test temperature. The two forms of the gas diffusion model provide insight into the foam parameters that must be influenced in order to reduce the gas diffusion rates in foams. An obvious but costly choice is to increase the foam density. Significant improvements without necessarily affecting the foam's density can be achieved, however, by increasing the fraction of polymer material in the cell walls or by decreasing the polymer permeabilities of the diffusing gases.

### Trouble Shooting Guide

1. Extrudate doesn't expand:
  - no **SAFOAM**<sup>®</sup> added
  - extruder temperature not high enough
  - melt temperature too cold
  - **SAFOAM**<sup>®</sup> CO<sub>2</sub> evacuating the extruder through vent
  - melt temperature extremely hot
  - sizing die preventing foam growth
2. Extrudate expands then collapses:
  - melt temperature hot
3. Extrudate has large voids or pops:
  - melt temperature hot
  - large particles in melt
  - too much foaming agent
4. Cell size too large:
  - decrease melt temperature
  - increase **SAFOAM**<sup>®</sup> level
  - increase pressure drop rate and increase output rate
5. Die land is too long:
  - ragged or uneven sheets with elongated cells

The **SAFOAM**<sup>®</sup> family of endothermic chemical foaming agents are designed to produce parts of superior quality. They are easy to use and provide the plastic processor with new opportunities and applications that are not possible with most other types of chemical foaming agents.

The answers to the most commonly asked questions about **SAFOAM**<sup>®</sup> are given below. They are based on our experience in the commercial use of **SAFOAM**<sup>®</sup> with various customers.

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## GENERAL INFORMATION

### Q. 1 What is the difference between endothermic and exothermic chemical foaming agents (CFA)?

A. Exothermic CFA such as Azodicarbonamide (or 1,1-azobisformamide), 4,4-Oxybis (benzenesulfonyl hydrazide (OBSh), or 5-Phenyltetrazole (5-PT) release heat during decomposition and require care during handling and processing to avoid problems caused by overheating.

Endothermic CFA, such as **SAFOAM**<sup>®</sup>, need energy (i.e. they absorb heat) during decomposition resulting in improved processing properties such as:

- Extrusion speed
- Wider operating temperature

### Q. 2 What is **SAFOAM**<sup>®</sup> in simple chemical terms?

A. **SAFOAM**<sup>®</sup> is a mixture of polycarbonic acid and carbonates. It is very stable, and during decomposition, produces only carbon dioxide gas in a very controlled fashion.

### Q. 3 What makes **SAFOAM**<sup>®</sup> different from other endothermic CFA?

A. Unlike the other endothermic CFA, which are usually a mixture of an acid and sodium bicarbonate, **SAFOAM**<sup>®</sup> contains modified citric acid salts, which are very tightly controlled on particle size and purity. This gives a predictable, controlled gas release. **SAFOAM**<sup>®</sup> is a buffered foaming agent, which helps prevent corrosion due to acid or base reaction.

### Q. 4 How does controlled gas release help?

A. A controlled decomposition means that most of the gas is contained in the polymer melt and does not escape at the rapid rate of other exothermic and endothermic CFA.

### Q. 5 What is the gas yield of **SAFOAM**<sup>®</sup> and the other CFA?

A. Based on 100% active powders, these are typical gas yields at 350°C:

<b>SAFOAM</b> <sup>®</sup> RPC	-	180 cc/g
<b>SAFOAM</b> <sup>®</sup> FP	-	200 cc/g
Azodicarbonamide	-	225 cc/g
5-PT	-	210 cc/g
Other endothermics	-	80 cc/g

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## QUESTIONS AND ANSWERS

The gas available in **SAFOAM**<sup>®</sup> gives the same or greater weight reductions at the same use level of other CFA even though the other CFA yield higher gas volumes.

These values are approximate and were obtained by a gas evolution and rate apparatus.

### **Q. 6 What are the effects of using a CFA at too high a level?**

A. Using more CFA than necessary for the desired effect is not only costly, but can cause other problems (i.e. excessive surface splay, extended cycle time or post-blow in injection molding). In extrusion, excessive CFA levels can cause sag or dimensional control problems.

### **Q. 7 Why are SAFOAM<sup>®</sup> concentrates typically 40% active?**

A. Experience has shown that most processors prefer to use concentrates. A 40% concentrate gives the best combination of dispersion and cost effectiveness. High active concentrates (70%) can cause dispersion problems which lead to variation in the finished product. With recommended use levels of about 1%, it is difficult to achieve accuracy and part consistency with 50 - 70% concentrates.

### **Q. 8 Which SAFOAM<sup>®</sup> should I use?**

A. **SAFOAM**<sup>®</sup> is available as a powder, but most processors prefer to use a concentrate for convenience of handling, etc. Refer to either the front or back covers for guidance in selecting a **SAFOAM**<sup>®</sup> compatible with your application or call Reedy International Corporation at (732-264-1777) for recommendations.

### **Q. 9 How much SAFOAM<sup>®</sup> should I use?**

A. Tables on the insides of the front and back covers give guidelines for use of **SAFOAM**<sup>®</sup>. The use levels recommended are good starting points, but you should optimize for your application. In any case, never use more **SAFOAM**<sup>®</sup> than necessary for the desired end effect. If you need more help contact Reedy International Corporation at (732) 264-1777.

### **Q. 10 How do I get samples of SAFOAM<sup>®</sup> and technical assistance?**

A. Contact Reedy International Corporation at (732) 264-1777. If you have a new or difficult application, technical assistance can be provided on-site, if necessary.

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## EXTRUSION

### **Q. 22 We have never extruded foam before; what equipment or modifications are needed?**

A. Conventional extruders can be used to foam extruded sheet, pipe, profiles, monofilaments, or tapes. Successful density reductions depend on setting temperature and pressure profiles within the extruder for the most efficient use of **SAFOAM**<sup>®</sup>. An extruder with an L/D ratio of at least 16:1 is best. Longer L/D ratios are better for higher output and better thermal control. We do not recommend barrier screws or vents.

### **Q. 23 Our extruder is vented; does this mean we cannot extrude foam?**

A. Not really, provided the vent can be sealed. If this is impossible, zone temperatures from the hopper to the vent must be kept below the decomposition temperature (<300°F, 149°C) of **SAFOAM**<sup>®</sup>. This may not be practical on short L/D screws.

### **Q. 24 How is premature foaming in the barrel prevented?**

A. Pressure must be maintained on the melt as **SAFOAM**<sup>®</sup> reacts to keep the gas in solution in the polymer. A high compression screw or temperature controlled back-pressure will help to produce pressure. Screw speed can also be used to regulate pressure.

### **Q. 25 Are there any problems with the die?**

A. Die land and mass should be minimized. If the pressure drops too low within the die land, cells can form while there is still shear stress on the melt. This can cause irregular cell formation and poor surface appearance.

Die temperatures with foam are usually lower than solid extrusions to improve surface appearance.

### **Q. 26 We currently use an exothermic CFA; what benefits will SAFOAM<sup>®</sup> give us?**

A. The **SAFOAM**<sup>®</sup> brochure lists several of these including:

- increased extrusion rates
- better control and consistency

There are some less obvious advantages, such as the possibility of reducing titanium dioxide levels in film and sheet. Improved ultra-violet stability is imparted by the light-scattering effect of the cell structure.

### **Q. 27 What about co-extruded foamed sheet and film?**

A. **SAFOAM**<sup>®</sup> makes high quality sheet and film. Because of its endothermic properties, there is no bleed-through or 'pin-holing' of the solid skins.

### **Q. 28 What effect has SAFOAM<sup>®</sup> foam on thermoforming properties?**

A. Because there is a reduction in the polymer weight, the thermoforming time is reduced. Otherwise, thermoforming, even with deep-drawn parts, is not affected.

# NOTES ON PROPERTIES, UNITS AND DATA LISTINGS

Property	Significance/Comments	Units		
		English	Metric	ASTM Test
<b>Compressive Strength</b>	The ability of a material to resist a force that tends to crush it.	lb/in <sup>2</sup>	kg/cm <sup>2</sup>	D695
<b>Density</b>	The equivalent property to specific gravity; measured by displacement.	lb/ft <sup>3</sup>	g/cm <sup>3</sup>	D792
<b>Deflection Temperature, 66 lb/in<sup>2</sup></b>	The measure of temperature at which a specimen deflects 0.01 inches under a load of 66 lb/in <sup>2</sup> .	°F	°C	D648
<b>Deflection Temperature, 264 lb/in<sup>2</sup></b>	The measure of temperature at which a specimen deflects 0.01 inches under a load of 264 lb/in <sup>2</sup> .	°F	°C	D648
<b>Dielectric Strength</b>	The voltage that an insulating material can withstand before dielectric breakdown occurs.	V/10 <sup>-3</sup> in	V/mm	D149
<b>Dissipation Factor</b>	The ratio of the power dissipated in watts in an insulating material to the product of the effective voltage and the current. Measured at a frequency of 10 <sup>6</sup> cycles per second.	Constant		D150
<b>Effect of Strong Acids</b>	A descriptive notation to indicate the material's performance.	Text		D543
<b>Elongation, Break</b>	The increase in distance between two gauge marks at the break point divided by the original distance between the marks. A zero value in the field indicates that it measured less than one.	%		D638
<b>Elongation, Yield</b>	The increase in distance between two gauge marks at a yield point divided by the original distance between the marks. A zero value in the field indicates that it measure less than one.	%		D638
<b>Flexural Modulus</b>	The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen.	lb/in <sup>2</sup>	kg/cm <sup>2</sup>	D790
<b>Flexural Strength, Yield</b>	The measurement of resistance of the material to fracture during bending.	lb/in <sup>2</sup>	kg/cm <sup>2</sup>	D790

## NOTES ON PROPERTIES, UNITS AND DATA LISTINGS (CONT'D)

Property	Significance/Comments	Units		
		English	Metric	ASTM Test
<b>Hardness</b>	The resistance of a material to compression, indentation and scratching. There are several scales that are commonly used.			
<b>Izod, Notched, LT</b>	The energy required to break specimens in which there is a v-notch to create an initial stress point but measured at low temperature (-40°C). (The value 999 in the tables indicates that the specimen did not break.) The measurement of notched izod for structural foam is of limited value.	ft lb./in	kg cm/cm	D256
<b>Izod, Notched, RT</b>	The energy required to break specimens in which there is a v-notch to create an initial stress point. (The value 999 indicates that the specimen did not break.)	ft lb./in	kg cm/cm	D256
<b>Linear Mold Shrinkage</b>	The difference between the size of the part and the size of the mold cavity. Values given are often the average of a range.		in/in	D955
<b>Melt Flow</b>	Rate of extrusion of molten resin through a die of a specified length and diameter. The conditions of the test (e.g. temperature and load) should be given. Frequently, however, the manufacturers' data lists only the value, not the condition as well.		g/10 min	D1238
<b>Refractive Index, Sodium D</b>	The ratio of the velocity and light in a vacuum to its velocity in the material.		Constant	D542
<b>Tensile Modulus</b>	(Also called modulus of elasticity). The ratio of nominal stress to the corresponding strain below the proportional limit of a material.	lb/in <sup>2</sup>	kg/cm <sup>2</sup>	D638
<b>Tensile Strength, Break</b>	The maximum stress that a material can withstand without breaking when subjected to a stretching load.	lb/in <sup>2</sup>	kg/cm <sup>2</sup>	D638
<b>Tensile Strength, Yield</b>	The maximum stress that a material can withstand without yielding when subjected to a stretching load.	lb/in <sup>2</sup>	kg/cm <sup>2</sup>	D638
<b>Thermal Conductivity</b>	The rate of heat flow under steady state conditions through unit area per unit temperature gradient in a direction perpendicular to an isothermal surface.			C177
<b>U.L. Temperature Index</b>	The maximum temperature below which a material maintains its electrical and mechanical integrity over a reasonable period.		°C/mm	

## NOTES ON PROPERTIES, UNITS AND DATA LISTINGS (CONT'D)

Property	Significance/Comments	Units		
		English	Metric	ASTM Test
<b>Vicat Softening Point</b>	The temperature at which a flat ended needle will penetrate a specimen under a specified load using a uniform rate of temperature rise.	°F	°C	D1525
<b>Volume Resistivity</b>	The measure of the ratio of the potential gradient parallel to the current in the material to the current density.		Ohm/cm	D257
<b>Water Absorption, 24 hours</b>	The percentage of water absorbed by a material when immersed in water for 24 hours; water absorbed in a material chiefly affects its electrical properties.		%	D570

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# GLOSSARY

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## - A -

**Alloy** - A composite material produced by blending polymers or copolymers with other polymers under selected conditions to achieve greater physical properties.

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## - B -

**Boss** - Protuberance on a plastic part designed to add strength, facilitate alignment, provide fastenings, etc.

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## - C -

**Clamping Plate** - A plate fitted to a mold and used to fasten the mold to a plate.

**Clamping Pressure** - The pressure applied to the mold to keep it closed during the cycle.

**Cooling Channels** - Channels located within the body of a mold through which a cooling medium is circulated to control the mold surface temperature.

**Cooling Fixture** (shrink fixture) - A jig or block to hold the shape of a molded part after it is removed from the mold until it is cool enough to retain its shape

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## - D -

**Daylight Opening** - The clearance between two platens of a clamping press in the open position.

**Delamination** - The surface of the finished part separates or appears to be composed of layers of solidified resins. Strata or fish-scale-type appearance where the layers may be separated.

**Density** - Weight per unit volume of a substance expressed in grams per cubic centimeter.

**Diaphragm Gate** - Used in symmetrical cavity filling to reduce weld line formation and improve filling rates.

**Direct Gate** - The sprue feeds directly into the mold cavity.

**Drooling** - The extrusion or leakage of molten resin from a nozzle or nozzle sprue bushing area while filling or shooting.

**Dwell** - A pause in the application of pressure to a mold, made just before the mold is completely filled, allowing any gases formed or present to escape from the molding material.

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## - E -

**Ejector Pin** (knockout pin)- A pin or plate that is driven into a mold cavity from the rear as the mold opens to force out the finished part.

**Extrusion** - The compacting of a material and forcing it through an opening in more or less a continuous fashion.

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## - F -

**Family Mold** - A multi-cavity mold where each of the cavities forms one of the component parts of the assembled finished parts.

**Fan Gate** - This gate is used to help reduce the stress concentrations in the gate area by spreading the opening over a wider area. Less warpage of parts can usually be expected by the use of this type of gate.

**Fick's Law** - The basic law of diffusion of different molecular species into each other. Fick's law states that the flux of a given component will be in the direction in which the concentration of that component decreases most steeply at a rate given by the product of the mutual diffusivity and the gradient. Most published diffusivity data are for two-component systems. Fick's law, which has many equivalent forms, is the defining equation for diffusivity.

**Fill** - The packing of the cavity or cavities of the mold as required to give a complete part or parts free of flash.

**Fillet** - A concavely curved transition at the angle formed by the junction of two plane surfaces, i.e., a rounded inside corner. Also, the material making up the transition. Where the surfaces are likely to

endure bending toward or away from each other, the fillet distributes and reduces the stress that would otherwise be magnified at the corner.

**Flash** - Extra plastic attached to a mold part along parting lines.

**Flow** - A qualitative description of the fluidity of a plastic material during the process of molding. A measure of its processability.

**Flow Line** - Marks visible on the finished item that indicate the direction of flow in the cavity indicating a cold mold or melt.

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### - G -

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**Gate** - An orifice through which the molten resin enters the mold cavity.

**GEAR** - Gas Evolution and Rate.

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### - H -

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**Hot Runner Mold** - A mold in which the runners are insulated from the chilled cavities and are kept hot.

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### - I -

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**Injection Molding** - A process where a heat softened plastic material is forced from a reservoir into a cool cavity that produces the desired shape

**Injection Pressure** - The pressure on the face of the injecting ram when injecting material into the mold.

**Injection Ram** - The ram or screw that applies pressure to the molten plastic material to force it into the mold cavities.

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### - J -

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**Jetting** - A turbulent flow in the resin melt caused by an undersized gate or where a thin section becomes thicker.

**Jig** - A tool for holding parts of an assembly during the manufacturing process.

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### - K -

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**Knit Lines** (weld lines) - The marks visible on a finished part made by the meeting of two flow fronts during the molding.

**Knockout Pin** (ejector pin) - A rod or device for knocking out a finished part from a mold.

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### - L -

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**Laminar Flow** - The flow of a resin in a mold is accompanied by solidification of the layer in contact with the surface that acts as an insulator through which material flows to fill the remainder of the cavity.

**Land** - The horizontal bearing surface of a semi-positive or flash mold by which excess material escapes; the bearing

surface along the top of the flights of an extruder screw; the final shaping surface of an extrusion die usually parallel to the direction of melt flow; the mating surfaces of any mold, adjacent to the cavity depressions, that, when in contact, prevent the escape of material.

**Land length** - In an extrusion die, the distance across the land in the direction of melt flow between the lands.

**L/D Ratio** - The term used to define an extrusion screw. This is the screw length to screw diameter ratio

**Low Marks** - Wavy surface appearance of a molded object caused by improper flow of the plastic into the mold.

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### - M -

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**Machine Shot Capacity** - Generally based on polystyrene. This is the maximum weight of plastic which can be displaced or injected by a single stroke.

**Melt Index** - A measure in grams of plastic material that can be forced through an orifice of 0.0825 inches when subjected to a force of 2,160 grams in 10 minutes at 190°C.

**Metering Screw** - The extrusion screw that has a shallow constant depth and pitch section usually over the last three or four flights.

**Modulus** - Derived from the Latin word meaning “small measure”, a modulus is a measure of a mechanical property of a material, most frequently a stiffness property; the absolute value of a complex number or quantity, equal to the square root of the sum of the squares of the “real” and “imaginary” parts.

**Moisture Marks or Welds** - Marks on the finished part that are caused by moisture in the resin and look like weld lines except they may be in the wrong areas for weld lines.

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### - O -

**Orange Peel** - A surface finish on a molded part that is rough and splotchy. Usually caused by moisture in the mold cavity.

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### - P -

**Packing** - The filling of the mold cavity or cavities as full as possible without causing undue stress on the molds or causing flash to appear on the finished parts

**Parison** - The hollow plastic tube from which a container is blow molded.

**Pinch-off** - A raised edge around the mold cavity that seals off the part and separates excess material mold closes around parison in the blow molding operation.

**Plasticate** - To soften by heating and mixing.

**Profile Die** - Extrusion die for the production of continuous shapes.

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### - Q -

**Quench Bath** - The cooling medium used to quench molten thermoplastic materials to the solid state.

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### - R -

**Ram** - The portion of an injection machine that moves backward and forward to deliver the shot of resin to the nozzle and mold. The screw in a reciprocating screw machine.

**Ram Travel** - The distance the injection ram (or screw) moves in filling the mold.

**Restricted Gate** - A very small orifice between runner and cavity in an injection mold. When the part is ejected, this gate readily breaks free of the runner system.

**Runner** - The channel that connects the sprue with the gate for transferring the molten plastic to the cavities.

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### - S -

**Shear** - The movement, in a fluid or solid body, of a layer parallel to adjacent layers.

**Shot** - The complete resin from a molding cycle, including scrap.

**Short Shot** - Failure to fill the mold or cavities of the mold completely.

**Shrink Fixture** (cooling fixture) - A jig or block to hold the shape of a molded part after it is removed from the mold until it is cool enough to retain its own shape.

**Shrinkage** - The difference found on a molded part as compared to the actual mold cavity dimension.

**Single Cavity Mold** - A mold having only one cavity and producing only one finished part per cycle.

**Sink Marks** - A shallow depression or dimple on the surface of a finished part due to shrinkage or low fill of the cavity.

**Slip Plane** - Marks evident in or on finished parts due to poor welding or shrinkage upon cooling.

**Splay Marks** - Marks or droplet type imperfections found on the surface of the finished parts that may be caused by the spraying of the hot melt through the gates and into the cool cavity where they set up.

**Split-Ring Mold** - A mold in which a split cavity block is

assembled in a chase to permit the forming of undercuts in a molded piece. These parts are ejected from the mold and then separated from the piece.

**Specific Gravity** - The density of any material divided by the density of water at standard temperature usually 4°C.

**Sprue** - The feed opening provided in injection molding between the nozzle and cavity or runner system.

**Sprue Bushing** - A hardened steel insert in the mold that accepts the extrusion nozzle and provides an opening for transferring the molten plastic.

**Sprue Gate** - A passageway through which resin flows from the nozzle to the mold cavity.

**Striations** - Marks evident on the molded part surfaces that indicate resin flow directions or impingement.

**Submarine Gate** (tunnel gate) - A type of edge gate where the opening from the runner into the mold is located below the mold parting line.

**Suck Back** - When the pressure on the sprue is not held long enough for the resin to cool before the screw returns, some of the hot resin in the cavities or runner system may expand back into the nozzle and cause sink marks on the finished piece.

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### - T -

**Tab Gate** - A small, removable tab about the same thickness as the molded item but usually perpendicular to it for easy removal.

**Thermoplastic** - A material capable of being repeatedly softened by heat and hardened by cooling.

**Thermoplastic Elastomer** - (TPE) Any of a family of polymers that resemble elastomers in that they are highly resilient and can be repeatedly stretched to at least twice their initial lengths with full, rapid recovery, but are true thermoplastics and thus do not require curing or vulcanization as do most rubbers.

**Thermoset** - A material which can undergo a chemical reaction by the action of heat or catalyst, leading to a relatively infusible and cross-linked state.

**Tunnel Gate** (submarine gate) - A type of edge gate where the opening from the runner into the mold is located below the mold parting line.

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### - V -

**Vent** - A shallow channel or opening cut in the cavity to allow air or gases to escape as the material fills the cavity.

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### - W -

**Warp** - Dimensional distortion in a molded object.

**Weld Line** (knit lines) - The marks visible on a finished part made by the meeting of two flow fronts during molding.

# COMMON ACRONYMS

ABS Acrylonitrile-butadiene- styrene	EC Ethyl cellulose	HMC High strength molding compound	MPPE Modified polyphenylene ether
ASA Acrylic-styrene- acrylonitrile	EMA Ethylene-methyl acrylate	HME High-vinyl modified epoxy	MPPO Modified polyphenylene oxide
ASTM American Society for Testing and Materials	EP Ethylene propylene	HMW High molecular weight	MSDS Material Safety Data Sheets
CA Cellulose acetate	ESCR Environmental stress crack resistance	LCP Liquid crystal polymer	MMA Methyl methacrylate monomer
CAB Cellulose acetate- butyrate	ETFE Ethylene- tetrafluoroethylene	LDPE Low density polyethylene	MMA Methyl methacrylate monomer
CAP Cellulose acetate- propionate	EVA Ethylene-vinyl acetate	LIM Liquid injection molding	MW Molecular weight
CBA Chemical blowing agent	FDA Food and Drug Administration	LLDPE Linear low density polyethylene	PA Polyamide (nylon)
CFA Chemical Foaming Agent	FR fiber reinforced	LMC Low-pressure molding compound	PAI Polyamide-imide
CPE Chlorinated polyethylene	FRP Fiber-reinforce plastic	LMW Low molecular weight	PAN Polyacrylonitrile
CPVC Chlorinated polyvinyl chloride	GEAR Gas evolution and rate	MA Maleic anhydride	PB Polybutylene
DSC Differential Scanning Calorimetry	HDPE High density polyethylene	MBS Methacrylate-butadiene- styrene	PBT Polybutylene terephthalate
DTA Differential Thermal Analysis	HIPS High-impact polystyrene	MDPE Medium-density polyethylene	PC Polycarbonate
	HM High-modulus		

## COMMON ACRONYMS

PCTFE Polychlorotrifluoro- ethylene	PIE Polyisobutylene	RH Relative Humidity	UHMW Ultra-high molecular weight
PE Polyethylene	PMMA Polymethyl methacrylate	RIM Reaction injection molding	UL Underwriter's Laboratories
PEC Polyphenylene ether copolymer	PMS Paramethylstyrene	RP Reinforced Plastics	UV Ultraviolet
PEEK Polyetherether ketone	PMT Paramethylpentene	RTM Resin-transfer molding	VAE Vinyl acetate-ethylene
PEH Polyphenylene ether homopolymer	PP Polypropylene	SAN Styrene-acrylonitrile	
PEI Polyetherimide	PPE Polyphenylene ether	SMA Styrene maleic anhydride	
PEO Polyethylene oxide	PPO Polyphenylene oxide	SMC Sheet molding compounds	
PES Polyethersulphone	PS Polystyrene	SPE Society of Plastics Engineers	
PET Polyethylene terephthalate	PU Polyurethane	SPI Society of Plastics Industry	
PETP Polyethylene terephthalate	PVAL Polyvinyl alcohol	TGA Thermal Gravimetric Analysis	
PF Phenyl-formaldehyde	PVDC Polyvinylidene chloride	TPE Thermoplastic elastomers	
PFA Perfluoroalkoxy (resin)	PVDF Polyvinylidene fluoride	TPU Thermoplastic polyurethane	
PI Polyimide	PVF Polyvinyl Fluoride		
PIB Polyisobutylene	RH Rockwell hardness	UHM Ultra-high modulus	

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# ACKNOWLEDGMENTS

The author would like to acknowledge the following people and companies for their assistance.

Gerry Mooney, Consultant  
Mike Caropreso, Consultant  
Larry Currie, Consultant  
Dan Cunningham, Consultant  
Joe Ventura, Consultant  
Dan Roberts, Consultant

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