Physical Foaming vs. Chemical Foaming

The Foaming Market:

The foam injection molding market can be separated into high pressure foam molding and low pressure foam molding. In general, low pressure foam molding is considered to be the structural foam market. This market is defined by parts with relatively thick wall sections, 6 mm and thicker, and machines designed with large platens and low clamping force. Historically, this market has used either nitrogen as a physical foaming agent or exothermic chemical foaming agents (CFA's) or a combination of both to generate cell structure.

High pressure foam molding also has a long history but has become more interesting recently with the advent of physical foaming technologies such as the MuCell® process and some of the more advanced endothermic chemical foaming agents such as Trexel's TecoCell® product offering. This market uses more traditionally configured injection molding machines and deals with parts with a wall thickness range of 1 to 4 mm. Given the thin walls and large flow length to thickness ratios of these applications, the typical density reduction is in the range of 5 to 10%.

The Chemical or Physical Foaming Agents in the High Pressure Foam Market:

<u>Operating Costs:</u>

High pressure foaming processes can be run using either physical or chemical foaming agents. There are both cost and performance benefits that determine the appropriate choice. The first consideration is cost. Chemical foaming agents require a small capital investment (typically a feeder system and shutoff nozzle) but represent a significant operating cost. These foaming agents can cost in the range of €4.65/kg ($2.50/lb.) up to €9.30/kg ($5.00/lb.) and are used at a typical range of 1% to 3% by weight depending on wall thickness and desired density reduction. This can represent as little as €0.02 ($0.025) of added cost for a 454 gram (1 lb.) part up to €0.085 ($0.10) depending on the cost of the specific chemical foaming agent and the letdown ratio. Physical foaming technologies tend to be capital intensive (requiring a high pressure SCF delivery system) but with very low operating costs. For a typical 454 gram (1 lb.) part, the cost of nitrogen consumed can be in the range of €0.002 to €0.006 ($0.0025 to $0.007) per part. Therefore one key consideration when looking at the two foaming technologies is the amortization of the capital costs for the physical foaming technology as compared to the ongoing operating cost of the chemical foaming agent. In general, physical foaming is more cost effective at high machine utilization rates and chemical foaming at low machine utilization rates. However this is highly dependent on material cost share of production costs.

<u>Material Considerations:</u>

The type of material being processed is also a consideration. This particular area can be looked at from the perspective of process temperature, sensitivity to moisture and final the presence or absence of fillers.

Chemical foaming agents rely on a chemical reaction to generate a gas that acts as a foaming agent. If the reaction occurs too early in the barrel, the gas generate can vent back through the solids bed and out the feedthroat resulting in a loss of some or all of the gas component and therefore little or no foaming in the part. If the process temperatures are too low, the reaction may not occur at all or will occur at such a slow rate that only a partial generation of the gas occurs. In contrast, physical foaming, such as the MuCell process, doses a precise amount of gas directly into the barrel each cycle regardless of process temperature. Therefore, physical foaming is suitable for all process temperatures. While there are a wide range of chemical foaming agents available on the market, the most common agents have reaction temperatures in the range of 160 to 200 C.

A second consideration related to the material is the sensitivity to moisture. Most material suppliers recommend the drying of resins. In some cases it is simply to eliminate any moisture splay on the surface of the material (typical of polyolefins and styrenic materials). <u>In this case</u> there is not a negative effect on the material performance. Other materials react with water resulting in a decrease in the molecular weight of the material and a corresponding decrease in performance. <u>In this case</u>, drying is not just for cosmetic reasons but is to achieve the optimum performance from the material. <u>In this case</u>, it is important to select a chemical foaming agent that does not generate water. This issue is eliminated when using physical foaming agents.

The final consideration is the general material type (semi-crystalline or amorphous) and the use of fillers. Materials that incorporate fillers tend to achieve good cell structure with both chemical and physical foaming agents. This is due to the fact that the fillers act as nucleating agents for the individual cells and they also help to control cell structure through faster cooling. In unfilled materials, particularly unfilled, semi-crystalline materials, there is a tendency for a level of non-uniformity of cell structure with physical foaming agents. This is due to the fact that the only contributors to cell nucleation when using physical foaming agents with unfilled materials is rate of pressure drop and level of SCF. Chemical foaming agents tend to self-nucleate. This results in a more uniform cell structure from the gate to the end of fill with some unfilled materials and specifically with HDPE and PP. In addition, because CO_2 comes out of solution more slowly, the endothermic CFA's tend to provide not only a more uniform cell structure but also a thicker skin layer.

The benefit of self-nucleation with CFA's when using filled materials and unfilled amorphous materials is much less significant as compared to physical foaming agents. And specifically in the case of glass filled materials there is no difference in cell structure uniformity between physical foaming and chemical foaming agents..

Part Geometry:

The wall thickness and the flow length/thickness ratio of the part will also be a determining factor. A typical chemical foaming agent my generate CO_2 at a rate of about 25% of the total amount added. This means that for 2% foaming agent concentrate added to a polymer, 0.5% by weight of CO_2 is generated. There are two considerations here, first CO_2 is a much less aggressive foaming agent that N_2 as CO_2 comes out of solution more slowly than nitrogen. This means that more time is required to grow the cells. As wall thickness decreases, the cooling time of the material decreases allowing less time for cell growth to occur. At 1 mm almost no density reduction will occur with a CFA due to the speed of cooling of the material in the mold. With a physical foaming process, higher levels of CO_2 or preferably nitrogen can be used to create foam structures at a wall thickness as low as 0.35 mm. Both scenarios have the effect on increasing density reduction as compared to a typical CFA.

Process Consistency:

Process consistency can be defined as the ability to produce the same cell structure part to part. This is controlled by both the consistency of the molding machine as it relates to shot size, injection velocity control and melt temperature as well as the addition of the foaming agent. In the case of a physical foaming agent this relates to adding the same amount of SCF on a shot to shot basis and managing dissolution of that SCF into the polymer melt. In the case of a chemical foaming agent that relates to adding the correct ratio at the feedthroat as well as managing the chemical reaction that produces the CO_2 or nitrogen that is the actual foaming component.

In both cases, chemical and physical foaming, the dosing mechanism for the foaming agent must be precise and repeatable. With a properly designed system, both chemical foaming agents and physical foaming agents can be precisely and repeatable dosed.

With a chemical foaming agent, the consistency of the reaction both level of conversion and the position in the barrel at which the reaction starts and finishes is important to the repeatability of the process. As noted above, as the position of the reaction changes, the amount of gas released and the amount that potentially escapes the feedthroat can change and this can create variation in the foam molded part.

There are also changes to the molding machine that can improve process consistency. As a starting point, the use of a shutoff nozzle and valve gates on hot runners will provide for a much greater process window and process control. There are also changes to screw design that will improve the management of the foaming agent in the barrel. While not all manufacturers of physical or chemical foaming agents requires machine modifications, Trexel understands these are critical to a repeatable foam injection molding process.

Residual Byproducts:

Chemical foaming agents by the nature of the process result in residual byproducts of the reaction chemistry. In some instances, this may be water which as mentioned above can create issues with certain polymers. In other cases, these components can lead to mold corrosion and plate out on the mold surface. The correct CFA chemistry must be chosen to match the requirements of the material/mold construction.

Physical foaming agents do not produce a reaction and therefore do not create reaction by-products. However, physical foaming agents can cause low molecular weight components in the polymer to be more mobile resulting in a higher level of components exiting the mold vents. This is one of the reasons it is recommended that mold vents be deeper when using physical foaming agents. The tendency for a higher mobility of low molecular weight components can also be seen with chemical foaming agents as well since this is related to the nature of supercritical fluids.

In some markets/materials, the residual byproducts of the chemical foaming agents may not be acceptable. For example, certain medical devices that contact body fluids or some packaging applications. These materials may also be banned from some recycle streams.

Regulatory Issues:

There are increasing regulatory issues with chemical foaming agents. In particular azodicarbonamide based product foaming agents are on watch lists in Europe. It is important to understand local regulatory issues regarding specific chemical foaming agent compositions.

Comparison Table:

The table below provides a comparison of Chemical foaming agents and the MuCell process with respect to specific material types and part designs.

Characteristic	CBA	MuCell®
Cell Structure - General	0	+
Cell Structure – Unfilled Olefins	0	-
Commodity Resins	+	+
Engineering Resins	0	+
Wide Process Window	-	+
Potential Weight Reduction	0	+
Dimensional Stability	+	+
Surface Quality	0	-
Thin Wall Parts (<2.5 mm)	0	+
Very Thin Wall (<2 mm)	-	+
Reaction By-products	-	+
Clamp Force Reduction	+	+
Gas Foaming Pressure	0	+

Given these material effects, the most common area of crossover between the two technologies are in parts produced with commodity materials (HDPE, PP, PS, ABS) with or without fillers. As process temperatures increase, the ability to find appropriate grades of chemical foaming agent become more difficult.

Summary:

In general, chemical foaming agents have a favorable comparison to physical foaming technologies in:

- Relatively thicker wall (4 mm and thicker)
- Low material consumption or low machine utilization
- Unfilled commodity resins.
- Elimination of sink marks with little cosmetic affect

Physical foaming technologies tend to compare favorably to chemical foaming agents for:

- Wall thickness less than 2 mm and particularly at less than 1.5 mm
- Process temperatures below 175 C or above 270 C
- High material consumption rates/high machine utilization
- Maximizing weight reduction by foaming
- Weight reduction through design optimization

Given these factors, the most common areas of crossover between the two technologies are in parts produced with commodity materials (HDPE, PP, PS, ABS) with or without fillers in a wall thickness in the range of 2 to 3 mm. As process temperatures increase and wall thickness decreases, the benefits of chemical foaming agent become less as compared to physical foaming particularly where nitrogen is the physical foaming agent.

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