Facts About. Foaming plastics with inert gases
In recent years, the application of foamed plastics have significantly expanded and diversified. Along with the growing market, there has been a growing interest in the development of environmentally-safe blowing agents. This article gives an overview of the most common production processes and specifically describes applications for the eco-friendly blowing agents carbon dioxide (CO₂) and nitrogen (N₂) as well as appropriate supply systems, including pressurization and metering systems.

The advantages of foamed products are undeniable and have led to their widespread and still growing popularity. Their essential characteristics are, apart from a low consumption of raw materials, positive product qualities such as low density, outstanding heat and sound insulation, mechanical damping, low water vapor permeability and reduced absorption of humidity. Different processes produce open-cellular, closed-cellular, or integral foams, have numerous uses and applications. Some of the most important applications for foamed products can be found in the fields of packaging, insulation, sound insulation and upholstery material.
A description of the main production process and various foaming processes.

The cellular structure of synthetic foams is created by blowing agents. Moreover, additives are often necessary, especially nucleation agents and stabilizers. From an economical point of view, extrusion foaming, injection-molded foaming, polyurethane foaming and EPS foaming are especially significant production processes.

**Chemical foaming – physical foaming**
A blowing agent is necessary to induce the foaming process. Depending on process and density, either chemical or physical blowing agents are applied.

**Chemical blowing agents** are mixed into the plastic pellets in the form of powder or pellets and dissolve at higher temperatures. Above a certain temperature specific for blowing agent dissolution, a gaseous reaction product – usually nitrogen or CO₂ – is separated and acts as a blowing agent. Due to the generation of undesired by-products and higher costs, chemical blowing agents are primarily applied for high-density materials.

**Physical blowing agents** are metered into the plastic melt during foam extrusion or injection molded foaming or supplied to one of the initial products during polyurethane foaming. Physical blowing agents are used to create the often-requested low densities. Other advantages include a more homogenous foam structure, better process stability and significantly lower blowing agent costs.

On the following pages, we will describe the foaming process with physical blowing agents, particularly with the relatively “new” blowing agents CO₂ and nitrogen.
Physical extrusion foaming.

For extrusion foaming, appropriate extrusion machines are needed, which differ significantly from standard machines. Depending on the output performance and on the product, only one extruder or, in other cases, two extruders (in so-called tandem units) are employed. Within the tandem units, which are often applied for higher output performances, the primary extruder is used for blowing agent supply and homogenization, whereas the secondary extruder serves as a systematic cooling device for the blowing agent-loaded melt.

Using a metering pump, the highly pressurized blowing agent is injected into the extruder through an injection valve. The quantity of the blowing agent can be metered directly and adjusted to the polymer and the desired foam density. The screw movement ensures a good dispersion in the polymer melt. Due to diffusion, the mixture of melt and blowing agent becomes further homogenized. In order to prevent premature foaming, the pressure within the extruder has to be maintained until coming out of the extrusion die. At the die exit, a sudden and extreme pressure drop leads to blowing agent supersaturation in the melt. The foaming starts, i.e. the already existing nuclei grow and form the foam bubbles. In order to increase foam homogeneity, so-called nucleating agents are often applied, which fulfill their nucleating function and form a large number of small bubbles. By means of extrusion, products for many application purposes can be foamed, which are primarily used in the packaging, construction and automotive industries.
Polyurethane foaming.

The chemical reaction of polyol and isocyanate creates polyurethane foam (PUR foam). In most cases, a physical blowing agent is added to one of the two reaction partners in order to reduce density. Both reaction partners are stored in tanks and driven in a cycle to the mixhead and then sent back to the tank. Numerous additives are added to influence the foam properties. The reaction components are then brought together and charged in the mixhead, starting the chemical reaction.

In the continuous process, semi-finished parts in the form of blocks or plates are produced. In the discontinuous process, formed parts are foamed by injection molding. Generally, the distinction is roughly made between soft foaming and hard foaming, with variations between the two. PUR foams serve as insulation material, and are used for furniture, mattresses, packaging material or applied in the automotive industry.
Physical blowing agents have become widely accepted for many applications, especially when low densities and high foam homogeneity are required. Selecting the physical blowing agent has a strong influence on foam quality and on the costs of the foamed product. Apart from that, environmental safety plays an increasingly important role.

The Montreal Protocol and its influence on consequential agreements pose a great challenge for the producers of foam. Despite the effective properties and easy handling of the formerly applied chlorofluorocarbons, there was a worldwide agreement to ban these because of their ozone depletion potential (ODP). Partially halogenated chlorofluorocarbons are also not environmentally safe and therefore already forbidden in many countries.

The alternatives are hydrocarbons such as isobutane and pentane, and the inert gases such as CO₂ and nitrogen. In many cases, CO₂ is the blowing agent of choice, because it has a significantly higher solubility in polymers compared to nitrogen.

Inert gases have many advantages:
- Environmentally friendly, due to no ODP and only a minimal GWP (Global Warming Potential)
- Low gas consumption, due to a high foaming degree
- Highly economical, because of cost efficiency
- Nonflammable
- Nontoxic
- Chemically inert
- No residues generated in the foam product

The CO₂ is not specially produced, but rather accumulates during other production processes. However, it is still necessary to purify, dry and liquefy before reuse as a blowing agent.

### Physical blowing agents - Overview

<table>
<thead>
<tr>
<th>Blowing agent</th>
<th>Chemical formula</th>
<th>Mole weight (g/mol)</th>
<th>Boiling point (°C)</th>
<th>Steam pressure (psi)</th>
<th>Combustible</th>
<th>ODP</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>44.0</td>
<td>-56.6</td>
<td>No</td>
<td>0.00025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>28.0</td>
<td>-195.7</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isobutane</td>
<td>C₄H₁₀</td>
<td>58.1</td>
<td>-11.7</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclopentane</td>
<td>C₅H₁₀</td>
<td>70.1</td>
<td>49.3</td>
<td>Yes</td>
<td>0.00025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isopentane</td>
<td>C₅H₁₂</td>
<td>72.1</td>
<td>29.0</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFC-11</td>
<td>CFC₁₁</td>
<td>137.4</td>
<td>23.8</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCFC-22</td>
<td>CHF₂Cl</td>
<td>86.5</td>
<td>-40.8</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCFC-142b</td>
<td>C₂F₆Cl₂</td>
<td>100.5</td>
<td>-9.2</td>
<td>Yes</td>
<td>1.0</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>HCFC-134a</td>
<td>CH₃CF₂Cl</td>
<td>102.0</td>
<td>-26.5</td>
<td>No</td>
<td>0.35</td>
<td>0.38</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
ODP = Ozone Depletion Potential  
GWP = Global Warming Potential
There are many favorable points concerning the application of inert gases as blowing agents, particularly CO₂. However, some still debate that CO₂ is “difficult” to handle. Usually, it’s stored close to the critical point in the boiling state, prone to evaporate and relatively compressible, a fact that makes metering difficult.

In **extrusion foaming**, extremely accurate metering in spite of unstable extruder pressure is a decisive requirement for a homogeneous foam structure. Membrane pumps are commonly used for metering liquid blowing agents. In the past, these blowing agents were mainly CFC’s which today have been more commonly replaced with hydrocarbons. More recently, these membrane pumps have been adjusted to the requirements of metering CO₂. In order to prevent metering problems and cavitation damages due to the formation of gas bubbles, both the CO₂ and the pump heads have to be kept very cool.

A very interesting technical and economic alternative is the DSD 500 inert gas metering unit developed by the Linde AG especially for this application case. It ensures extremely accurate metering in spite of fluctuating backpressures in the extruder.

Presently, there are still some application limits for inert gases. Extrusion foaming of low density materials such as polyethylene and polypropylene are perhaps better achieved with hydrocarbon blowing agents. CO₂ requires higher process pressures due to its limited solubility and less effective heat transfer due to the absence of a phase transfer from the liquid to gaseous phase.

Even so, more and more products are foamed with CO₂, and in exceptional cases with nitrogen. Applications for environmentally friendly foaming includes XPS insulating boards for the construction industry, polyethylene (PE) foam foils for lid seals, PE cable insulations and, to some extent, polystyrene food packaging. Appropriately modified polypropylene can also be foamed with CO₂ up to densities of 200 kg/m³.

In **PUR foaming**, selecting the blowing agent strongly depends on the foam application. Foaming for insulation uses, such as insulating boards or the insulation for refrigerators, is usually done with pentane due to favorable insulation properties. Choosing the right blowing agent allows for the production of very light foams. The lowest densities, much less than 20 kg/m³, can be produced with CO₂.
The physical characteristics of CO₂ require a supply and metering concept adjusted to the respective needs and requirements. While taking economic and technical aspects into account, the optimal concept has to be chosen according to the consumption of gases and the required pressure.

High-pressure metering pumps

The CO₂ supply requirements for foaming plastics are high. Special metering pumps suitable for liquid CO₂ and exact metering with pressures of up to 500 bar are necessary. These metering pumps need liquid CO₂ that is completely free of gas bubbles and should have a fairly high primary pressure of approx. 870psi. Linde was certainly one of the pioneers providing solutions since the 1990s pertaining to the tricky metering of inert gases for foaming.

The result of this work is the DSD 500 high-pressure metering unit. In productive operation at numerous reference customers around the world, it has proven its absolute efficiency for the delivery of liquid CO₂ and gaseous nitrogen. In special, air-powered compressors, the unit compresses the blowing agent from the gas supply pressures of up to 7250psi and meters it very evenly, even when there is a strong backpressure fluctuation. This is due to the combination of a patented mass flow control concept and a highly precise proportional control valve.

The very compact and user-friendly unit has the following special advantages:

- The flow rate can be controlled very precisely and independently from the pressure and temperature in the extruder, even at very small metered amounts
- The unit automatically adjusts itself to the process pressure conditions
- The highly dynamic control valve immediately reacts to process changes
- In contrast to conventional metering pumps, the DSD 500 is tolerant to gas bubbles in the liquid CO₂. Extensive cooling before and in the metering unit can be omitted
- In contrast to other metering pumps, the DSD 500 is also suitable for metering gaseous blowing agents (e.g. nitrogen)
CO₂ supply and metering concept for extrusion foaming, consisting of a DLE 15 CO₂ compressor station and a DSD 500 high-pressure metering unit.
Linde AG offers a complete, one-stop supply and metering concept tuned to the DSD 500. Based on many years of experience in plastic foaming and customer feedback, the best supply version is chosen by specialists from Linde. This guarantees only minimal investment costs for the customer, maximum supply safety and low operating resource costs. Even when the customer plans to employ existing metering pumps, the choice of the right tank type and the best pressure-increase pump at the tank is still very important. Basically, one has the choice to employ medium-pressure or low-pressure tanks.

In a medium-pressure tank, the liquid CO₂ is stored under a pressure of 1200psi max. This tank type is not insulated. In order to warrant a defined operating status, the tank is equipped with an electric heater and a cooling unit. The CO₂ temperature is kept a constant within a narrow range, creating a defined tank pressure. For the supply of metering pumps for foaming, this pressure is typically at approx. 800 psi.

Medium-pressure tanks do supply the required pressure, but since the CO₂ is in the boiling state, the fluid is prone to evaporate or form bubbles on the way to the consumer. This requires an intensive CO₂ cooling before and within the metering pump.

Using a low-pressure tank is recommended in many cases. In order to supply the initial pressure for the high-pressure metering system, an additional pressurization system is needed at the tank. The CO₂, which is approx. -4 °F, is compressed up to approx. 800psi. While the CO₂ gains heat during this compression, the fluid’s temperature is still significantly lower than the boiling temperature corresponding to the pressure of 800psi. Therefore, supercooled, bubble-free fluid with a diminished compressibility is available at the metering pump.

In the foam-insulated or vacuum-insulated low-pressure tank, the liquid CO₂ is stored at a pressure of approx. 300 psi and a corresponding temperature of approx. -4 °F. This tank type offers principal advantages, such as lower production costs, flexibility in storage capacity and high supply safety.
Linde AG has developed two different, tried and tested pressurization versions for the delivery of CO₂ as a blowing agent in foaming processes. In cooperation with a renowned machine manufacturer, a CFA type pressure increase pump has been developed especially for continuous PUR foaming, which is applicable also for high output performances in the slabstock process.

An electrically powered piston pump compresses CO₂ to a maximum of 1000psi and transports it in a ring line from the CO₂ tank through one or several consumers and back to the CO₂ tank in the circuit. This way, liquid, bubble-free CO₂ is always available at the metering pump when needed.

The DLE 15 LCO₂ compressor station is based on air-powered piston compressors which compress the CO₂ up to the adjustable end pressure, usually 800psi. The compressors have been specially adjusted for operation with liquid CO₂.

When combined with a CO₂ low-pressure tank, there are clear financial and technical advantages for the user:

- Liquid CO₂ is released in a supercooled and bubble-free state, i.e. even rather delicate applications do not require a phase separator or recooling
- The fluid quantity adapts itself automatically and with high flexibility both to the demand and to the fluctuations in the demand
- The investment costs for the gas supply and therefore the lease costs for the user as well as the installation costs are significantly lower
- Unlike other systems, the LCO₂ compressor station is tolerant to a gaseous fraction in the suction-side liquid CO₂. Through this, the usual supporting measures such as high-quality insulation or recooling can be omitted
- The concept offers absolute supply safety, even when siphoning from the tank vehicle into the tank.

**Conclusion:**

In summary, it can be concluded that, due to the advantages described above, inert gases are becoming more and more accepted as physical blowing agents for different foaming processes. An elaborate and appropriate supply and metering concept, from the storage tank to the infeed into the foaming unit, enables users to easily switch to these environmentally friendly blowing agents.
Getting ahead through innovation.

With its innovative concepts, Linde is playing a pioneering role in the global market. As a technology leader, it is our task to constantly raise the bar. Traditionally driven by entrepreneurship, we are working steadily on new high-quality products and innovative processes.

Linde offers more. We create added value, clearly discernible competitive advantages, and greater profitability. Each concept is tailored specifically to meet our customers’ requirements – offering standardized as well as customized solutions. This applies to all industries and all companies regardless of their size.

If you want to keep pace with tomorrow’s competition, you need a partner by your side for whom top quality, process optimization, and enhanced productivity are part of daily business. However, we define partnership not merely as being there for you but being with you. After all, joint activities form the core of commercial success.

Linde – ideas become solutions.