THE LINDE GROUP

Linde

White Paper.

Unlock the full potential of gas injection moulding.

Authors: Marcel Op de Laak et al.
Published in the journal
Kunststoffe 3/2013

Unlock the full potential of gas injection moulding. A step ahead with CO_2.

Fluid injection technology (FIT) is an established method for producing complex hollow parts where solid cores are not feasible or desirable. The choice of fluid has a significant impact not only on part quality and cycle time, but also on the quality of the inner surface. What is not so well known is that carbon dioxide, as an injection medium, offers huge potential to reduce part costs, cut energy consumption and improve part quality without additional effort.

Fluid injection technology is an umbrella term for injection moulding methods in which an injection fluid displaces a liquid polymer from the core of a moulded part. Hobson [1] in a patent dating back to 1939 described how this can be achieved. This basic idea inspired several methods in the 1980s, classified according to the melt displacement method. The most important are:

- Blow moulding or the short-shot process,
- the full-shot or spill-over process,
- the pushback process and
- the floating core process.

Looking beyond the melt displacement method, researchers also experimented with different injection fluids in the late 1990s. These efforts led to the water injection technology (WIT) and gas-water injection technology (TiK-WIT) processes [2, 3].

Water is an extremely attractive injection fluid for high-volume production of parts, primarily because of its great cooling action and its low cost. However, water has drawbacks for the process, because the parts need to be subsequently drained or dried and because leaks can give rise to serious damage and costs.

This White Paper will now present another fluid, which is also well known but not typically associated with fluid injection moulding, namely carbon dioxide (CO_2). As a gas, CO_2 has a number of unusual physical properties that make it ideal for gas injection moulding (GIM). These properties are explained later in this document.

Benefits of CO_2 for GIM

Looking at the suitability of water and CO_2 for various parts, tests show similar performance in terms of energy consumption for the injection process and attainable cooling or cycle times (Table 1, p. 5). In addition, the process flow for CO_2-enabled GIM is more or less the same as that for GIM using nitrogen (N_2).

A look at the physical properties of CO_2 clearly reveal the benefits of this gas for FIM [4]. Its density only starts to rise in any significant way at 150 bar, approaching that of water as the pressure continues to rise (Fig. 1). Another interesting aspect is that CO_2 can be liquefied at room temperature simply by raising the pressure to 60 bar. Nitrogen, by comparison, cannot be liquefied at room temperature, and is a liquid only at cryogenic temperatures (-196°C at atmospheric pressure).

CO_2 phase diagram

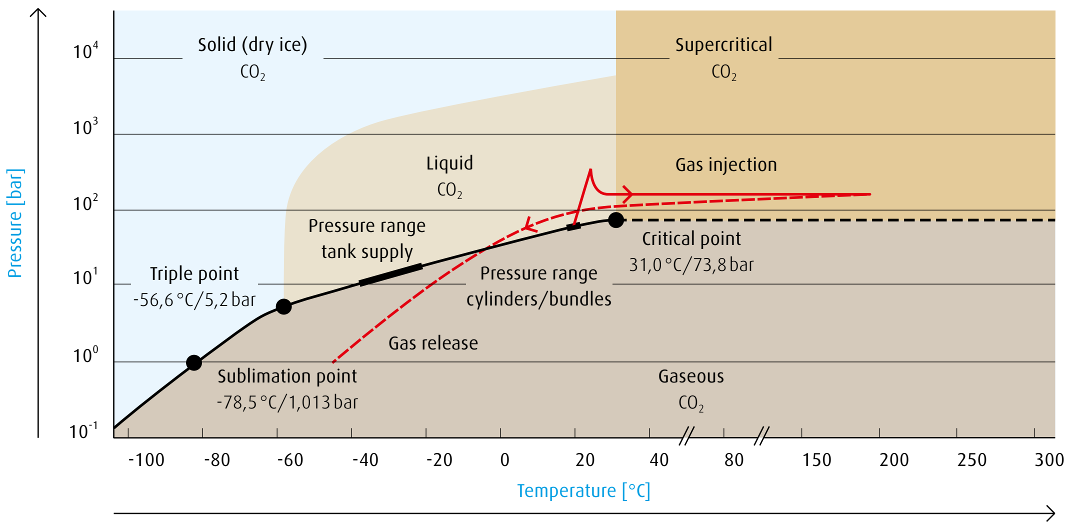

Fig. 2. The phase diagram for carbon dioxide shows the thermodynamics of the CO_2 gas injection technique where the gas is supplied from cylinders or cylinder bundles.

CO_2 is usually delivered as a liquid in cylinders, cylinder bundles or tanks. In this physical state, the heat capacity (cp) of CO_2 (3.0 kJ/(kg K)) is three quarters that of water (4.178 kJ/(kg K)) and almost three times that of nitrogen (1.041 kJ/(kg K)). Another physical advantage of CO_2 is the high expansion heat which the gas extracts from its environment as the pressure falls. The combined effect of these physical properties explains the huge cooling potential of CO_2, resulting in cooling cycles that are half those of nitrogen, for instance.

A practical advantage of GIM with CO_2 is that the gas is a very effective cleaning agent. Annular gap injectors virtually stop clogging up and can be thoroughly cleaned by simply purging with CO_2 between two production cycles. The process is more stable as a result because there is no danger that the injector will gradually clog up.

Any assessment of the energy needed to compress the fluid must distinguish between whether compression takes place with liquid or gaseous CO_2. If the CO_2 is in liquid form, the corresponding pumps have a very high flow rate and the amount of energy needed for pressurising is more than two orders of magnitude lower than that for compressing gaseous nitrogen. True, nitrogen can also be pressurised in the liquid state, but only from a cryogenic liquid tank, which slowly warms up over a long period and thus requires large amounts to be drawn off continuously.

Density of CO_2

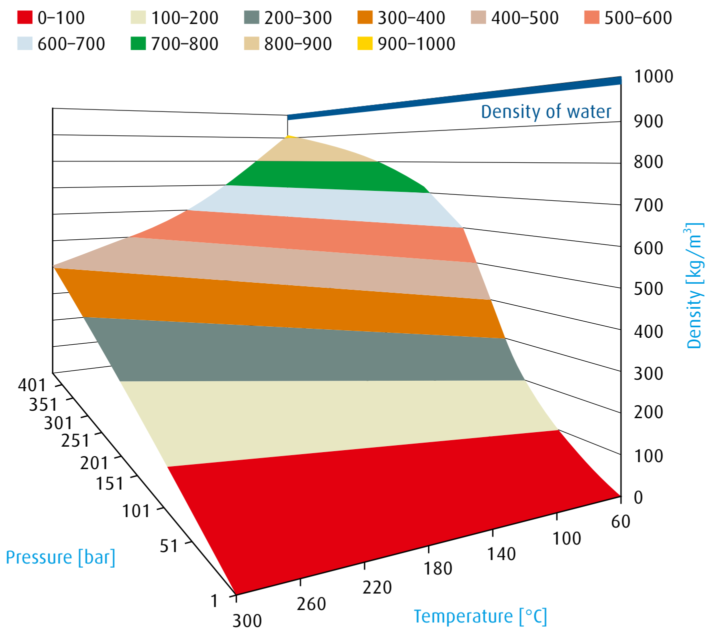

Fig. 1. The density of CO_2 as a function of pressure and temperature. CO_2 can be liquefied at room temperature by raising the pressure to 60 bar; as the pressure rises, its density approaches that of water.

Shorter cycle times

Before the injector forces the gas into the injection mould and thus into the part, the prevailing pressure (60 bar) in the cylinder bundle compresses the liquid gas to around 300/400 bar. This process is highly effective and thus energy-efficient. As it is being injected, the CO_2 expands into the melt, displaces the liquid polymer and thus forms a cavity in the part. During the subsequent holding pressure time, the remaining melt heats the CO_2 and this intense heat absorption causes the gas to pass into the supercritical state (Fig. 2).

At the end of the pressure holding time, the gas is discharged from the part. The drop in pressure causes a sharp drop in the temperature of the CO_2, and a great deal of heat is extracted from the part. This enormous cooling effect can additionally be utilised to specifically cool hotspots in the injection mould. To successfully employ CO_2-based GIM, operators must observe a few important process details. In particular, they must

- choose the right injector and
- avoid changes in the cross-section of the supply line from the GIM installation to the injector.

The choice of injector is important to ensure a smooth GIM and gas release process 5]. True, this is also the case for nitrogen but, because CO_2 has a much higher density at a given pressure, it takes longer to release it than to release N2 if the annular gap injectors are too small. The line from the GIM installation to the injector must not have any changes of cross-section because these would lead to expansion of the CO_2 and the formation of dry ice, which could clog the line.

If operators heed these tips, they can switch most common gas injection moulds that have been previously operated with N_2 over to CO_2. Thus, as the following case reports illustrate, the cycle time of many existing GIM processes can be shortened by an average of more than 25% merely by replacing the gas and supply system (Fig. 3) – for instance with the GIM solution jointly developed by Maximator GmbH, Nordhausen, and Linde AG, Munich.

Practical benefits you can count on – references cases

Following the steps described above, i.e. simply by replacing the supply system and injection gas, Engel Formenbau und Spritzguss GmbH of Sinsheim, Germany, shortened its cycle time for manufacturing a refrigerator handle in the current series by 36%. A thermal imaging camera is useful here because it enables the temperature distribution in the part to be analysed immediately after the handle has been automatically removed from the mould (Fig. 4). Direct comparison shows that the handle produced with carbon dioxide can be demoulded at a much colder temperature than its counterpart produced with nitrogen. This not only helps to shorten the cycle time, but also improves the warpage behaviour.

Similar success was achieved for a dip-stick guide tube produced by Gebr. Wielpütz GmbH & Co. KG, Hilden, Germany. The cycle time for this part was shortened by 22%. Made from PA6.6 GF30, the part has a very homogeneous (low) temperature of 75 to 80°C upon removal, which is well below the normal demoulding temperature of 120 to 150°C (Fig 5). With this part, it is not the gas channel which is crucial to shortening cycle times, but rather the machining stage following the injection process.

Excessive shortening of the cycle time would create hotspots at the thicker-walled areas of the holder and ribs. These hotspots are caused by small-sized sliders that cannot be cooled with water. CO_2 serving as a fluid for GIM is an effective spot cooling agent, without the need for further process equipment and requiring only a slight modification to the mould. CO_2 spot cooling shortens cycle times even more, thereby increasing the moulded part quality further still.

Fig. 3. Innovative CO_2 GIM solution from Linde and Maximator comes with an integrated liquid booster and is suited to CO_2 and N_2 applications.

Fig. 4. The cycle time for this refrigerator handle was shortened by more than a third. This thermal image, captured immediately after the moulding process, shows the higher temperature of an injection-moulded handle produced with N_2 (left) compared with that achieved with CO_2 (right).

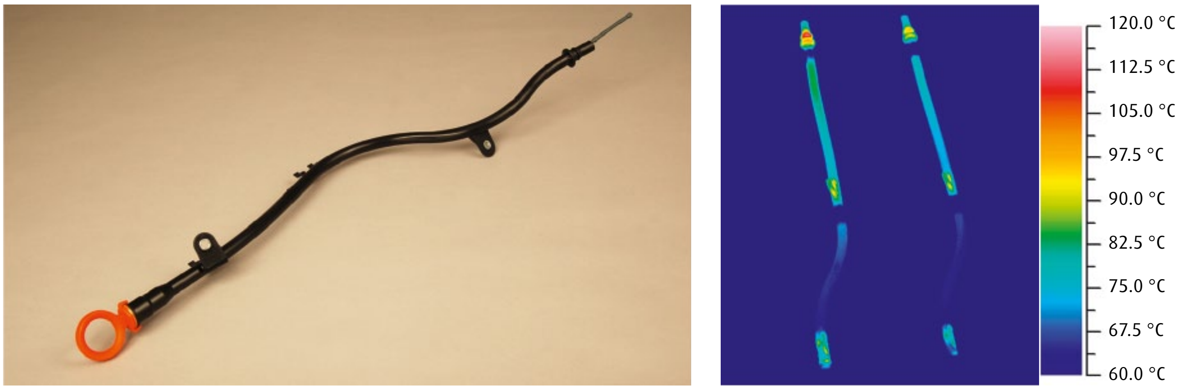

Fig. 5. At the end of the cycle, the temperature of an injection-moulded dipstick guide tube made from PA6.6 GF30 CO_2 is much lower than the normal demoulding temperature for such materials, as shown here by the thermal image captured immediately in the 2-cavity mould after the moulding process.

Table 1

Process	Easy to handle	Fluid costs	Investment in installation	Investment in mould	Material costs	Energy bill for FIT	Injector size	Cycle time
CO_2-GIM	++	○	75	100	100	1	+	50
CO_2-GIM with flushing	+	–	75	105	100	3	○	40
GIM	++	○	100	100	100	100	+	100
GIM with flushing	+	–	100	105	100	300	○	80
TiK-WIT	○	+	150	120	130	1	–	50
GIM cool	○	○	120	100	100	200	+	95

Comparison of FIT processes with different fluids. The percentages are expressed in relation to the nitrogen GIM baseline (= 100%)

Injection mould with spot cooling

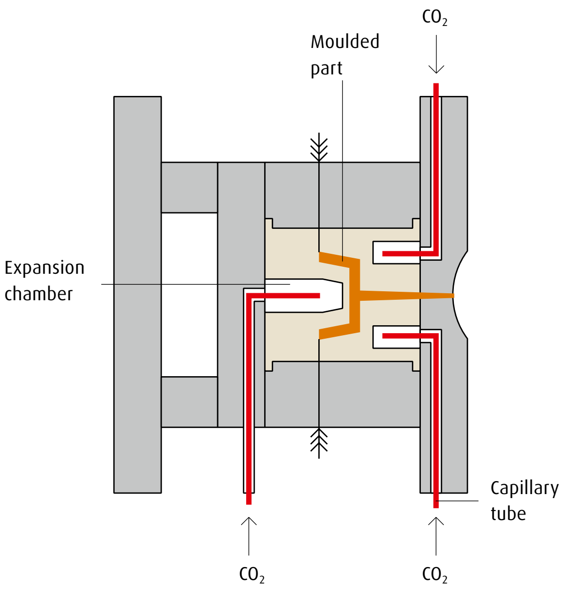

Fig. 6. Schematic structure of an injection mould with spot cooling [6,7]. The CO_2 cools the region around the expansion chamber effectively.

Fig. 7. The installation for dynamic mould temperature control combines rapidly alternating heating and cooling cycles at temperature gradients of up to 20 K/s.

Synergy effects for production cost and quality gains

Once plastics manufacturers have made a strategic decision in favour of CO_2 as the injection fluid, they have the opportunity to lower production costs and improve part quality even further. A variety of technologies are available to help them achieve this:

- Spot cooling of injection moulds,
- Dynamic mould temperature control and
- Cleaning of injection moulds and plastic surfaces (as pretreatment for painting).

In spot cooling (Fig. 6), liquid CO_2 is passed through a flexible capillary tube, 1.6 mm wide at most, to the spot on the mould which needs cooling. There, the CO_2 expands into a chamber, which needs to be provided in the cavity, and effectively cools the region around the expansion chamber [6, 7]. CO_2 GIM can be combined with spot cooling to use the gas discharged from the GIM process to cool a hotspot in the same mould.

A further application for CO_2 lies in the extremely fast dynamic cavity temperature control of injection moulds and mould inserts (Fig. 7). This process, developed jointly by Linde AG, gwk Wärme Kältetechnik mbH, Kierspe, Germany, and Iserlohner Kunststoff-Technologie GmbH, was presented at Fakuma 2012. In this process, CO_2 is used to both heat and cool the same mould insert.

For the heating cycle, gaseous CO_2 is heated by means of a compressor and turbo-heater, and then passed through heating-cooling channels in the mould insert that follow the contours of the part to be moulded. The gas is fed in a closed loop. The mould insert is cooled again by feeding liquid CO_2 into the same heating-cooling channels and expanding it. The cooling effect is similar to the aforementioned spot cooling process. With this technology, temperature gradients of up to 20 K/s can be achieved between heating and cooling cycles.

Conclusion

Requiring only slight modifications to the supply installation, switching to carbon dioxide for GIM is a simple way for plastics manufacturers to shorten cycle times and lower part costs. CO_2 GIM is as easy to manage as the process of switching from nitrogen to CO_2. It is thus the perfect technology to enhance both current and future GIM applications.
The cleaning effect of the CO_2 on the injectors stabilises production processes in the long term. In addition, CO_2 offers an effective and inexpensive way to manage temperature control in injection moulding.

References

1 PS-US 2331688: Method and apparatus for making hollow articles of plastic material (1939) Hobson, R.
2 DE 103 39 859 B3: Verfahren und Vorrichtung zur Herstellung eines Kunststoff-Bauteils, welches einen Innenhohlraum hat (2003) Op de Laak, M.
3 Op de Laak, M.; Rupprecht, V.: Die Qual der Wahl. Kunststoffe 96 (2006) 9, pp. 115-120
4 A.N.Other: Eigenschaften der Kohlensäure. Fachverband Kohlensäure-Industrie e.V., 1997
5 Eyerer, P.; Elsner, P.; Knoblauch-Xander, M.; von Riewl, A.: Gasinjektionstechnik. Hanser Verlag, Munich 2003
6 A.N.Other: Technisches Handbuch Toolvac, Firmenschrift der AGA Gas GmbH, 1995
7 Berghoff, M.: Kühlen kritischer Bereiche im Werkzeug mittels CO_2-Temperierung. Diplomarbeit, Märkische Fachhochschule Iserlohn 1999

The authors

Dipl.-Ing. Marcel Op de Laak, born in 1970, is a managing director of TiK-Technologie in Kunststoff GmbH, Teningen, Germany; marcel.opdelaak@tik-center.de

Dipl.-Ing. Axel Zschau, born in 1965, is a managing director of TiK-Technologie in Kunststoff GmbH, Teningen; axel.zschau@tik-center.de

Dipl.-Ing. Andreas Praller, born in 1966, works for the Linde Gases Division in Unterschleißheim, Germany, where he is project leader with responsibility for developing and launching gas-based technologies for the plastics processing industry; andreas.praller@linde-gas.com

Dipl.-Ing. (FH) Mads Rasmussen, born in 1977, works in the Sinsheim technical office of Maximator GmbH, where he provides plastics processors with support for technologies for gas and water injection technology and physical foaming; mrasmussen@maximator.de

Image and table credits

Fig. 1: Maximator
Fig. 2: Linde/Maximator/TiK
Fig. 3: Maximator
Fig. 4–6: Linde
Fig. 7: gwk
Table 1: TiK

Contact details

Linde AG

Linde Gases Division
Seitnerstrasse 70
82049 Pullach
www.linde-gases.com

Andreas Praller
Phone +49.89.31001-5654
Fax +49.89.31001-5585
Mobile +49.160.96240746
andreas.praller@linde-gas.com

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 standardised as well as customised 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 optimisation, 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.

Linde AG
Gases Division, Linde Gas Deutschland, Seitnerstrasse 70, 82049 Pullach, www.linde-gases.com

14012_1014_LCS