Gas based technologies for higher productivity in injection moulding

Birmingham, 26th September 2017
Andreas Praller, Linde AG
1. The Linde Group
2. Overview gas applications in the plastics industry (focus: CO₂ based applications for the injection moulding industry)
3. Spot Cooling of injection moulds with CO₂
4. Gas (assisted) injection moulding with CO₂
The Linde Group
a leading gases & engineering company

- €16.9bn sales in 2016
- 59,715 employees worldwide (2016)
- Global presence in more than 100 countries
Gases Division
Wide range of products

Gases

<table>
<thead>
<tr>
<th>Air Gases</th>
<th>Other Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>Acetylene</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Helium</td>
</tr>
<tr>
<td>Argon</td>
<td>Propane</td>
</tr>
<tr>
<td>Rare Gases:</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>Krypton, Neon,</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>Xenon</td>
<td>Hydrogen</td>
</tr>
</tbody>
</table>

Specialty Gases

- Pure Gases
- Specialty Gas Mixtures

Medical Gases

- Medical Oxygen
- Nitric Oxide (NO)
- Nitrous Oxide (N2O)
Gases Division
Wide range of markets and applications

Diversity and innovation for sustainable and profitable growth.
Application Technology
Scope

- New application opportunities for our products and services through ongoing R&D activities: increase of efficiency, quality, capacity

- Technical and commercialisation support for local sales engineers

- Partner management for technical development and commercialisation

- ~ €30m investment in Applications and Technologies with a global team of more than 130 employees

- ~ 600 active patent families and ~ 100 new patents granted p.a.
You all know where carbon dioxide is used

But there are more applications ......
Gas applications for the plastics industry

Effective pressure and cooling for Gas (assisted) injection moulding

Advanced mould temperature control for shorter cycle times and better part quality

Eco-friendly Extrusion and Polyurethane foaming with CO₂ (or nitrogen)

Foam injection moulding for parts with lower weight and less material

Dry ice cleaning Manual and automated cleaning solutions for moulds and plastic parts (before painting)
Spot cooling of injection moulds with CO$_2$

in cooperation with

THE LINDE GROUP
Cooling of injection moulds

Usually moulds are cooled with water (sometimes oil) flowing through cooling channels which are ideally evenly distributed over the tool.

Limitations of water cooling

- Water cooling requires channels of at least 5 mm in diameter. Smaller diameters bear the risk of clogging and/or require a very high water pressure.
- Therefore water cooling channels are often installed where space is available, and not where it might be most efficient.
- Especially hot spots like narrow cores are often not cooled at all. The cooling time in this areas then determines the total cycle time.

Clogging of water channels when using water with bad quality caused by limescale, corrosion and biological fouling
Principle of Spot cooling

- PLASTINUM Spot Cooling supplements the cooling with water in areas where conventional water cooling is unfavourable or impossible.
- CO₂ cools locally the hot spots/areas of the mould.
Principle of Spot cooling

**Example: Cooling of a long, thin core**

- **Solid/gaseous CO₂**
  - -78 °C / <5.18 bar

- **Gaseous CO₂**
  - ~1 bar

- **Liquid CO₂**
  - 20°C/60 bar

- **Capillary tube**
  - 1.6 or 0.8 mm outside diameter

- **Drilling / Erosion**

- **Hot spot (area)**

The diagram shows the principle of spot cooling using solid/gaseous CO₂ at -78 °C and <5.18 bar, gaseous CO₂ at ~1 bar, and liquid CO₂ at 20°C/60 bar. The capillary tube with an outside diameter of 1.6 or 0.8 mm is used for drilling or erosion processes.
Mode of operation

- Discontinuous CO₂ injection, only when polymer melt is injected
- Defined open/close pulses (number, length) of the solenoid valve per CO₂ cooling period
- CO₂ cooling starts after CO₂ controller gets signal from injection moulding machine
Advantages

- Very narrow areas of the mould can be cooled, cores with approx. 2 mm diameter can be cooled with thin and flexible capillary tubes
- Shorter cycle times (50 % and more possible) and thus higher productivity
- Even temperatures over the whole part
- Higher quality of the parts, e.g. reduced warpage and no sink marks
- Use with all kind of tool steels
- Little mould modifications, retrofit often possible
- Low investment costs
CO₂ supply and customer installation

CO₂ Tank → PRESUS® C Pressure booster → Pipeline to injection moulding machine → Capillary tubes → Injection moulding machine

Cylinder bundle, 60 bar (tests, small series, start of production) → CO₂ controller

Signal from injection moulding machine
Case study: Cooling of a long, thin core

Customer: Foehl, Germany (end customer: Kaercher)

- Part of a pressure washer, pipe of trigger gun
- Cooling of a core with 6 mm diameter and approx. 200 mm length
- Material: PA 66, 30 % GF

- With CO₂ cooling the cycle time is in a normal range (the core is no longer the bottle neck)

- Remark: The idea to use CO₂ cooling came from the mould maker.
Case study: Cooling of an area of a reflector housing (retrofit solution)

Critical area

It is not possible to cool the middle thin web with water.

Reflector Housing in the mould (2 cavities)
Case study: Cooling of an area of a reflector housing

Saved cooling time with CO₂ Spot Cooling: 45 %

Several capillary tubes are installed in the mould.
Gas (Assisted) Injection Moulding with CO₂

in cooperation with

MAXIMATOR®
Maximum Pressure.
High cooling effect of carbon dioxide

Why does carbon dioxide cool so efficiently?

- Under typical Gas Injection Moulding GIM pressures carbon dioxide has a very high density.

- Significantly higher specific heat capacity $c_p$ than nitrogen
  - Nitrogen: 1,041 kJ/(kg K)
  - Water: 4,178 kJ/(kg K)
  - CO$_2$ (in liquid state): ca. 3.0 kJ/(kg K)

- The big cooling effect during expansion of CO$_2$ contributes considerably to the total cooling.
Density of carbon dioxide

- At approx. 150 bar and higher the density of CO₂ is very high, offering the best cooling performance.
- The higher the pressure, the better the cooling and the cycle time reduction.
CO₂ phase diagram

The use of liquid CO₂ for GIM at pressures of at least 150 bar is patented by Linde (European patent EP 2474405, patent in China granted, patent application in US).
Advantages

- Excellent cooling properties

- Absolute dry process, i.e.
  - no drying / draining of the parts required
  - no problems in case of leakages or breakthrough / bursting of the parts
  - use of conventional tool steels

- Easy process control compared to water injection technology

- The required GIM equipment is not more complex than that for nitrogen, just adopted for carbon dioxide.

- No special polymers required

=> **Significantly shorter cooling times compared to GIM with nitrogen**

=> **Cycle times comparable to or shorter as with Water injection technology**
Required equipment, what has to be considered

- Supply and pressure boosting of liquid CO₂
- Pressure control equipment optimized for liquid CO₂
- Gas injectors (crucial for successful use of CO₂)
  Good results with suitable injectors with annular gaps as well as with actively movable injectors (cross sections and design must be optimized for CO₂)

CO₂ compressor control module
(manufacturer: Maximator)
CO₂ supply and equipment concept

Small series – large volume production

- Tank
- CO₂ booster station PRESUS® C HP
- Liquid CO₂, e.g. 350 bar
- CO₂ pressure control module
- Injection moulding machine

Cylinder bundle, 60 bar (tests, small series, start of production)

CO₂ compressor control module

Injection moulding machine
Customer references – suitable parts

- Refrigerator handles
- Car door panels
- Various car door handles (exterior and interior)
- Bike racks
- Fluid pipes
- Window handles
- Positive tests with many other parts
Case study: Refrigerator handle

Company: Engel Formenbau und Spritzguss GmbH, Germany
Material: ABS
Process: Push back

Cycle time reduction with CO$_2$: 36 %

IR picture 16 sec after mould opening
Left handle: N$_2$ – Right handle: CO$_2$
Gas Injection Moulding with CO$_2$
At a glance

- Significant reduction of cooling and cycle times compared to conventional GIM with nitrogen
- Gas Injection Moulding with CO$_2$ combines the benefits of water injection technology with the advantages of gas injection with nitrogen
- Retrofitting of existing products usually possible
- Process similar to nitrogen process
- Process equipment (pressure control modules) and gas injectors similar to nitrogen equipment
Thank you very much for your attention!

Visit us in Hall 4, Stand F79