

## Feature Project

## Extrusion of Polystyrene Microcellular Foam with Supercritical CO<sub>2</sub> by Xiangmin Han (Koelling, Tomasko, Lee)

The use of supercritical CO<sub>2</sub> for continuous production of microcellular foam is gaining increased attention. The final product's micron-size bubbles save material, improve mechanical properties, create unique thermal and electrical properties, and use an environmentally-friendly foaming agent.

Experiments are underway with a small die that is 0.5 mm in diameter and 10.0 mm in length. A syringe pump is loaded with CO<sub>2</sub> from a gas tank. The gas is compressed to just above the barrel pressure, then injected into a two-stage single-screw extruder. After preliminary mixing by the screw rotation, the mixture flows through two static mixers to ensure that a one-phase solution is formed. Nucleation occurs in the die due to a rapid, large pressure drop.

Applying the Sanchez-Lacombe equation of state, the solubility of CO<sub>2</sub> in polystyrene is calculated from 20 to 200°C under pressures from 0.69 to 20 MPa. A 3-dimensional figure (Figure 1) is plotted to express the relation between CO<sub>2</sub> content, temperature, and saturation pressure. As

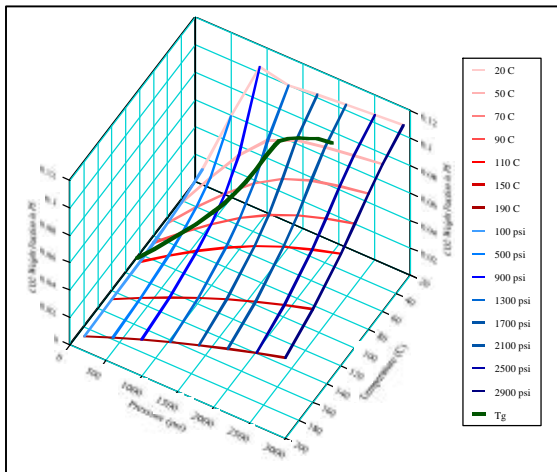


Fig.1. Saturation CO<sub>2</sub> content at different pressure and temperature (the thick line on the surface is the T<sub>g</sub>).

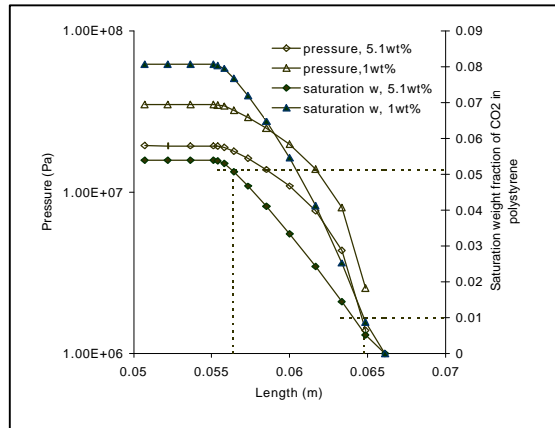


Fig. 2. Pressure distribution along the center line in the die insert and saturated CO<sub>2</sub> content (CO<sub>2</sub>/ PS, die insert: 66.12mm; capillary nozzle: 10mm)

expected, more CO<sub>2</sub> can be dissolved into polystyrene at a low temperature and high pressure. The solid thick line on the 3-D surface represents the trend of the glass transition temperature, which changes with CO<sub>2</sub> content or saturation pressure. The solution can absorb more CO<sub>2</sub> below the surface, while it becomes supersaturated above the surface.

The contraction flow in the extrusion die is simulated by the FLUENT computational code to determine the nucleation starting position. As shown in Figure 2, a large pressure drop (about 19.4 MPa) occurs with an average pressure drop rate of more than  $1.27 \times 10^9$  Pa/sec. This is the major driving force of nucleation. The saturated CO<sub>2</sub> content is calculated according to the local pressure along the center line at 175°C. The horizontal dashed lines represent the CO<sub>2</sub> content in the one-phase solution (1wt% or 5.1wt%), and the inter-

section of the vertical dashed lines and the length-axis represents the onset position of supersaturation in the capillary nozzle. This position can be treated as the point where bubble nucleation and growth begin. The more CO<sub>2</sub> in the melt, the earlier the bubbles begin to nucleate and grow. In other words, a high CO<sub>2</sub> content gives more nucleation points, but requires a longer time for bubble growth.

Figure 3 exhibits how the pressure drop and the average pressure drop rate change with CO<sub>2</sub> content. Both decrease with increasing CO<sub>2</sub> content at the same flow rate. So the conclusion that high CO<sub>2</sub> content is favorable for foaming means that nucleation occurs earlier at a position where the thermodynamic instability is greater. If the viscosity is reduced enough by the addition of CO<sub>2</sub>, the foaming process can be performed at a relatively low die temperature that is near the glass transition temperature (T<sub>g</sub>). The foam can then be quenched below T<sub>g</sub> quickly after it exits the die and before the bubbles grow significantly.

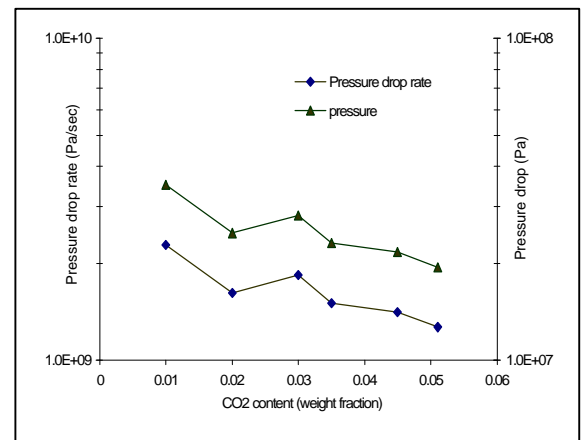


Fig. 3. The influence of CO<sub>2</sub> content to the pressure drop and pressure drop rate