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Analysis of extrusion foaming of polyolefins using isobutane and CO₂

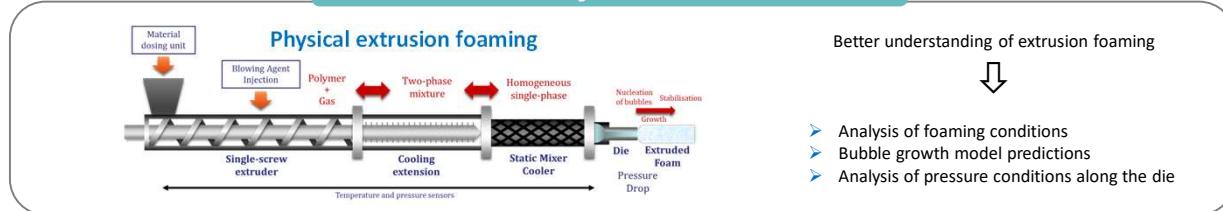
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Objective



Materials, foaming conditions

Two sets of foaming experiments:

LDPE grades:

CD0230 and LD0304 from TotalEnergies

Foaming with 5 and 8 wt% iso-butane

Range of T_{melt} during foaming : 120 to 100 °C at the die exit

CD0230 and LD0304 : $T_c = 97^\circ\text{C}$ (start 100°C)

PP experimental grades:

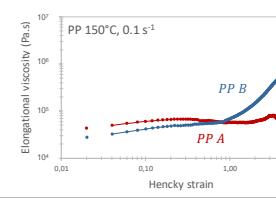
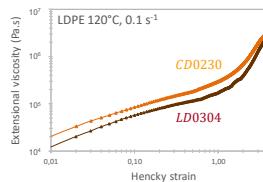
PP A (linear chains) and PP B (branched chains) from TotalEnergies

Foaming with 1 and 2 wt% CO₂

Range of T_{melt} : 170 to 130 °C at the die exit

PP A : $T_c = 97^\circ\text{C}$ (start 105°C), PP B : $T_c = 104^\circ\text{C}$ (start 110°C)

Rheological behaviour

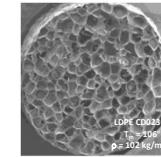


Foam characterization:

SEM → Cell density (cells/m³)

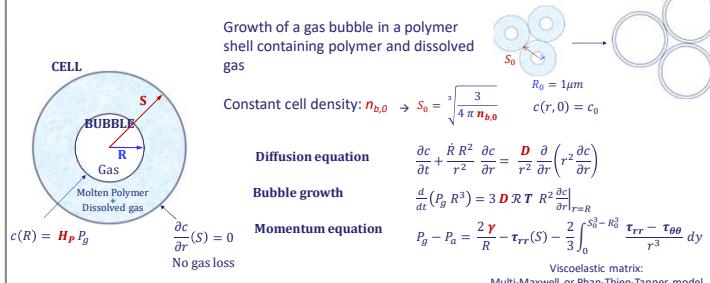
→ Mean bubble size

→ Foam density (kg/m³)



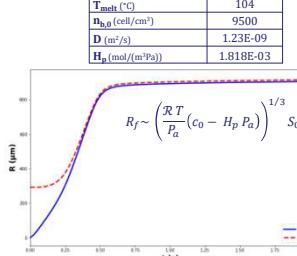
Bubble growth modeling

Model equations and hypothèses [1]



Bubble growth prediction

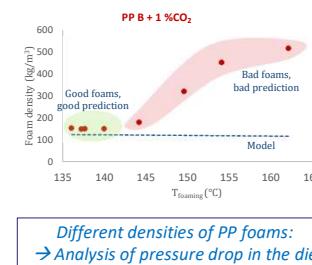
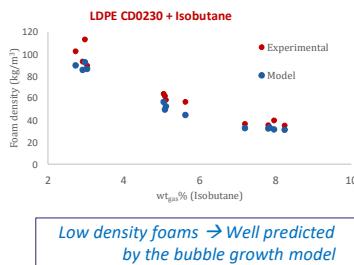
CD0230



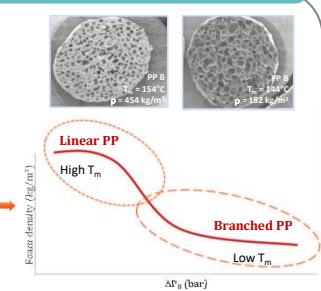
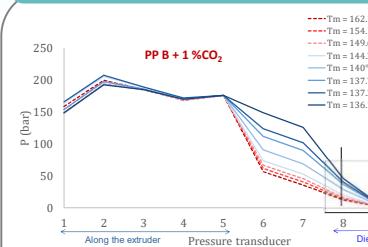
ρ _{polymer} (kg/m³)	922
ρ _{foam model} (kg/m³)	31.6
ρ _{foam measured} (kg/m³)	35.4
Relative error (%)	10.7

$$\rho_p = \frac{1}{1 - w_{tg}} \left(\frac{S_0}{S(t)} \right)^3$$

Foam density → comparison between model predictions and experiments



Analysis of pressure drop in the die



Why analysing ΔP in the die?

Pressure drop in the die = responsible for the foam formation (nucleation + growth)

$$\Delta P_B$$

$$\Delta P_{cis}$$

$$\Delta P_{cap}$$

$$\alpha$$

$$\text{Die geometry}$$

$$\Delta P_{conv} = \frac{2KL_c}{3m(R_0 - R_1)} \left(\frac{3m + 1}{m} \frac{Q}{\pi} \right)^m \left[\frac{1}{R_1^{3m}} - \frac{1}{R_0^{3m}} \right] \quad [2]$$

$$\Delta P_{cap} = 2KL_f \left(\frac{3m + 1}{m} \frac{Q}{\pi} \right)^m \frac{1}{R_1^{(1+3m)}} \quad \text{Power law: } K, m$$

$$\text{If } \Delta P_B > \Delta P_{cis} \Rightarrow \text{Additional contribution: } \Delta P_{el} = \Delta P_B - \Delta P_{cis} \quad (\text{Eq. 1})$$

Steps :

1. Calculation of ΔP_{cis} ✓

2. Comparison with ΔP_B ✓

If $\Delta P_B > \Delta P_{cis}$ ⇒ calculation $\Delta P_{el} = \Delta P_B - \Delta P_{cis}$ (Eq. 1)

3. If viscoelastic effect,

⇒ ΔP_{el} variation with T should follow an Arrhenius law

4. If $\Delta P_{el}(T)$ Arrhenius law

⇒ Crystallization at the origin of ΔP_{el} excess

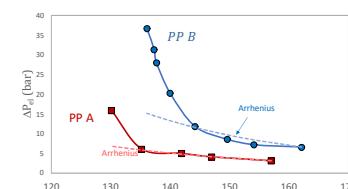
→ Calculation of η_{el} (Eq. 2)

→ Estimation of a crystallized fraction ϕ (Eq. 3)

$$\eta_{el} = \frac{\pi \Delta P_{el}}{Q} \frac{(1 - \cos \alpha)}{\sin^3 \alpha} \left(R_1 + R_0 \right) \left(\ln \frac{R_1}{R_0} \right)^{-2} \quad (\text{Eq. 2})$$

$$\eta_{susp} = \eta_{matrix} \left[1 - \frac{\phi}{B} \right]^{-2} \quad (\text{Eq. 3})$$

$$B = 0.54 \text{ for spherulites} \quad [4]$$



- Existence of an additional contribution (ΔP_{el}) in the die
- Low $\Delta P_{el} = f(T)$ (higher T) follow an Arrhenius dependence
- The presence of a crystalline state in the die could explain the pressure drop excess and help in some cases the foaming process

References:

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