



HAL
open science

Analysis of extrusion foaming of polyolefins using isobutane and CO₂

Carlos Sandino, Edith Peuvrel-Disdier, Jean-François Agassant, Séverine A.E. Boyer, Patrice Laure, Geoffrey Hibert, Yves Trolez

► **To cite this version:**

Carlos Sandino, Edith Peuvrel-Disdier, Jean-François Agassant, Séverine A.E. Boyer, Patrice Laure, et al.. Analysis of extrusion foaming of polyolefins using isobutane and CO₂. 55ème Congrès du Groupe Français de Rhéologie, Oct 2021, Bordeaux, France. . hal-03410720

HAL Id: hal-03410720

<https://hal.science/hal-03410720v1>

Submitted on 17 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

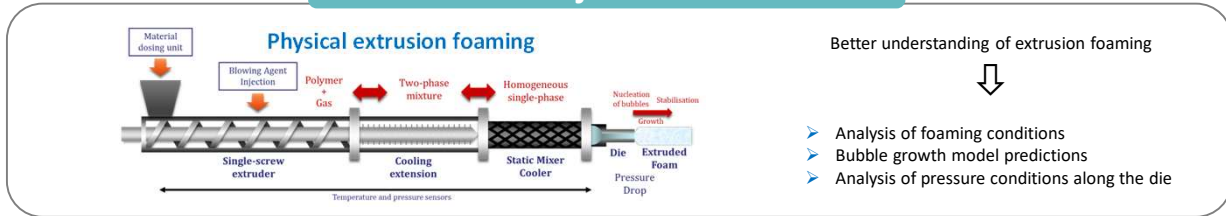
C. Sandino, E. Peuvrel-Disdier, J.F. Agassant, S.A.E. Boyer, P. Laure

MINES ParisTech, PSL Research University, CEMEF, UMR CNRS 7635, CS 10207, 06904 Sophia Antipolis cedex (France)

G. Hibert, Y. Trolez

TotalEnergies One Tech Belgium, Zone Industrielle Feluy C, B 7181 Feluy (Belgium)

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)

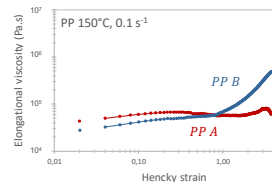
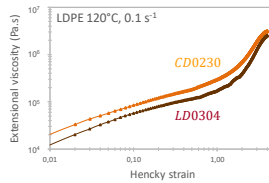
PP experimental grades:

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

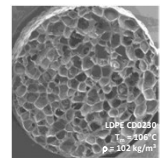
PP A: $T_c = 97^\circ\text{C}$ (start 105°C), PP B: $T_c = 104^\circ\text{C}$ (start 110°C)

Rheological behaviour



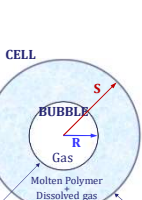
Foam characterization:

- SEM → Cell density (cells/m³)
- Mean bubble size
- Foam density (kg/m³)



Bubble growth modeling

Model equations and hypotheses [1]



Growth of a gas bubble in a polymer shell containing polymer and dissolved gas

Constant cell density: $n_{b,0} \rightarrow S_0 = \sqrt[3]{\frac{3}{4\pi n_{b,0}}}$, $R_0 = 1\mu\text{m}$, $c(r,0) = c_0$

Diffusion equation: $\frac{\partial c}{\partial t} + \frac{R}{r^2} \frac{\partial c}{\partial r} = \frac{D}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial c}{\partial r} \right)$

Bubble growth: $\frac{d}{dt} (p_g R^3) = 3 D R T \frac{\partial c}{\partial r} \bigg|_{r=R}$

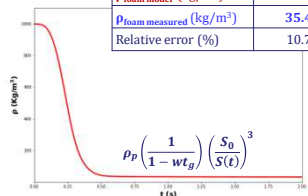
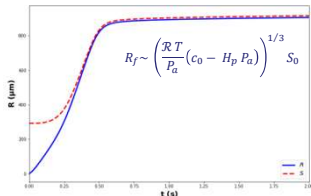
Momentum equation: $P_g - P_a = \frac{2\gamma}{R} - \tau_{rr}(S) - \frac{2}{3} \int_0^S \dot{\gamma}^2 - \dot{\gamma}_0^2 \frac{\tau_{rr} - \tau_{\theta\theta}}{r^3} dy$

Viscoelastic matrix: Multi-Maxwell or Phan-Thien-Tanner model

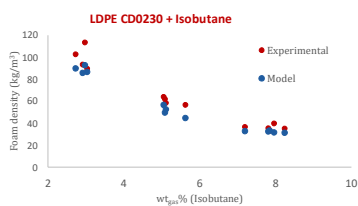
Bubble growth prediction

CD0230	%wt isobutane	8.23
	T_{melt} (°C)	104
	$n_{b,0}$ (cell/cm ³)	9500
	D (m ² /s)	1.23E-09
	H_p (mol/(m ³ Pa))	1.818E-03

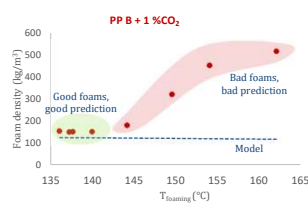
$\rho_{ppolymer}$ (kg/m ³)	922
$\rho_{foam model}$ (kg/m ³)	31.6
$\rho_{foam measured}$ (kg/m ³)	35.4
Relative error (%)	10.7



Foam density → comparison between model predictions and experiments

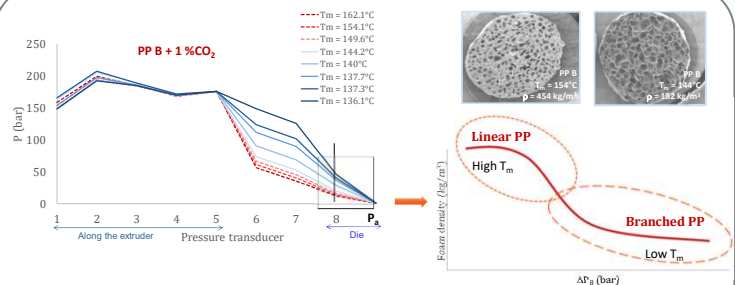


Low density foams → Well predicted by the bubble growth model



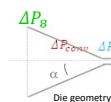
Different densities of PP foams: → Analysis of pressure drop in the die

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)



$$\Delta P_{cis} = \Delta P_{conv} + \Delta P_{cap}$$

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

$$\Delta P_{cap} = 2KL_f \left(\frac{3m+1}{m} \frac{Q}{\pi} \right)^m \frac{1}{R_1^{(1+3m)}}$$

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

Steps :

1. Calculation of ΔP_{cis} ✓

2. Comparison with ΔP_B ✓

If $\Delta P_B > \Delta P_{cis} \Rightarrow$ 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

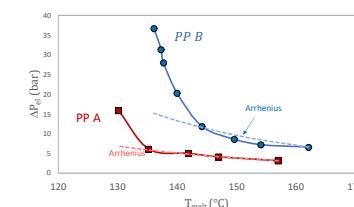
→ Calculation of η_{el} (Eq. 2)

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

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

$$\eta_{susp} = \eta_{matrix} \left[1 - \frac{\phi}{B} \right]^{-2}$$

B = 0,54 for spherulites [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:

- Regliero R. et al. (2016). *Int. Polym. Proc.* 31: 26-36
- Agassant J.F. et al., "Mise en forme des polymères-approche thermomécanique de la plasturgie" Lavoisier, (2015)
- Cogswell F.N., *Polym. Eng. Sci.* (1972) 12, 64-73, Y. Demay et al., *Int. Polym. Proc.* (2018) 3, 363-370
- Tanner R.I., *J. Non-Newt. Fluid Mech.* (2002) 102, 397-408; (2003) 112, 251-268