



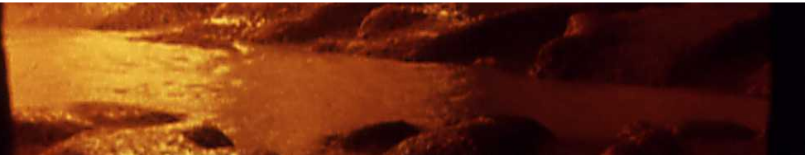
TherMatHT 8, 2-3 sept. 2021

Experimental and numerical study of bubble formation in a borosilicate melt doped with cerium oxide

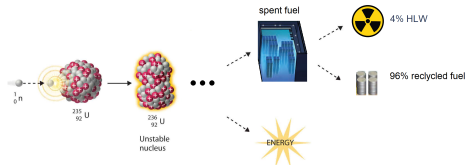
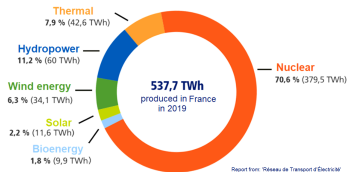
Luiz Pereira¹, Annabelle Laplace¹ & Franck Pigeonneau²

¹CEA Marcoule, DES, ISEC, DE2D, SEVT/LDMC

²Mines-Paristech PSL Univ. - CEMEF



1. Industrial context

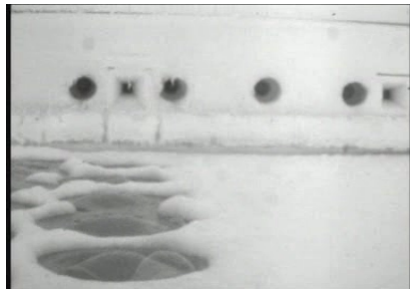


1. Industrial context

Primary foam



Secondary foam

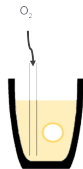


- ▶ Energetic efficiency ;
- ▶ Wear of the process.

1. Industrial context

Purpose of the work :

Bubble dynamics in molten nuclear glass doped in cerium oxide



1 bubble

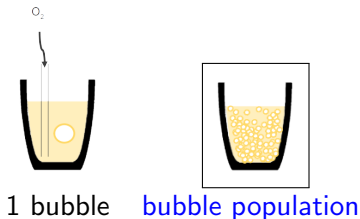


bubble population

1. Industrial context

Purpose of the work :

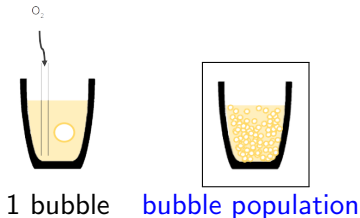
Bubble dynamics in molten nuclear glass doped in cerium oxide



1. Industrial context

Purpose of the work :

Bubble dynamics in molten nuclear glass doped in cerium oxide



- ▶ What are the main mechanics of the bubble formation ?
- ▶ What are the nature and sizes of bubbles ?
- ▶ What is the dynamics of the bubble population ?

1. Industrial context
2. Bubble formation in crucible
3. Numerical predictions
4. Synthesis

2. Bubble formation in crucible

- ▶ Melting of granular material composed by a borosilicate glass + 0.1wt % of CeO_2 .
- ▶ Post mortem observation of a crucible section.

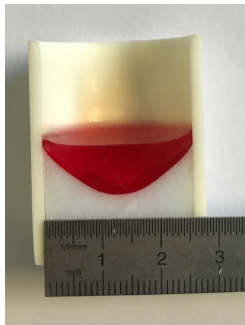


Figure 1 – Cross section of the crucible a room temperature.

2. Bubble formation in crucible

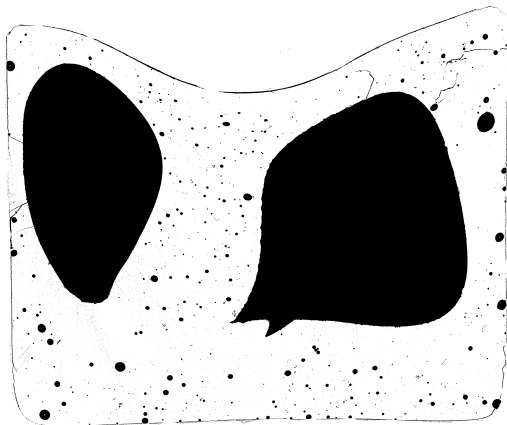


Figure 2 – Optical microscope sample at $T = 800^{\circ}\text{C}$ and after 20 min in the furnace.

2. Bubble formation in crucible

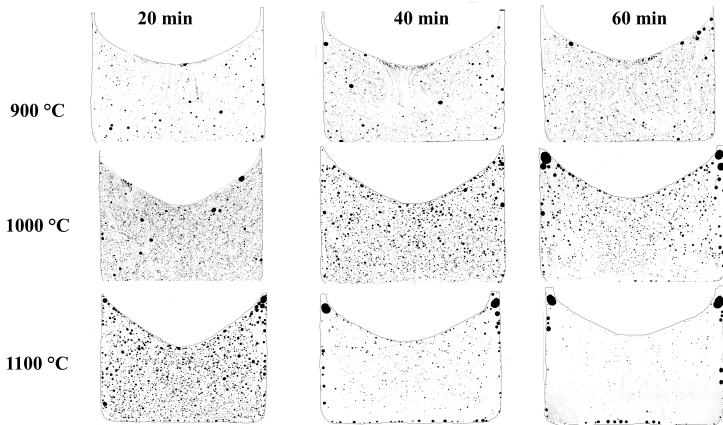


Figure 3 – Optical microscope images of samples at various temperatures and times.

2. Bubble formation in crucible

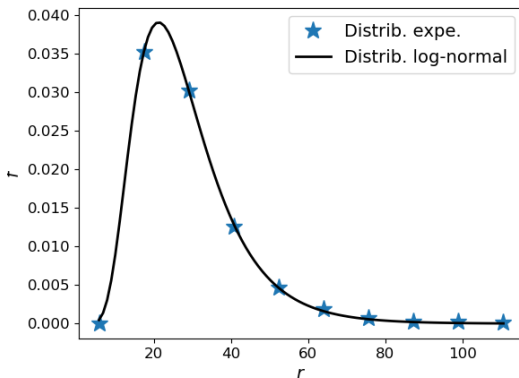


Figure 4 – Bubble size distribution at $T = 1000^\circ\text{C}$ after 20 minutes of melting.

$$f(x, \zeta, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \ln \zeta)^2}{2\sigma^2}\right]. \quad (1)$$

2. Bubble formation in crucible

According to Reboul et al.¹, void volumes in a granular media are log-normal distributed.

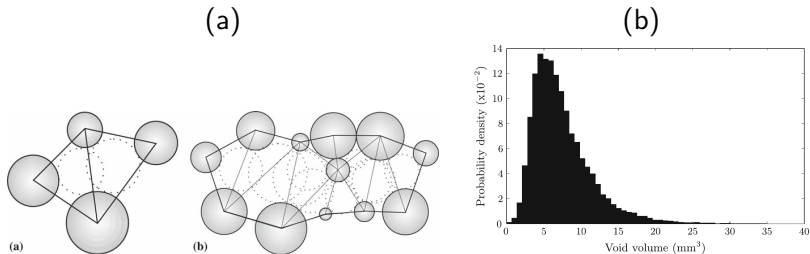


Figure 5 – Voids in a granular media (a) and PDF of void volumes (b) according to Reboul et al. (2008).

1. N. Reboul/E. Vincens/B. Cambou : A statistical analysis of void size distribution in a simulated narrowly graded packing of spheres, in : [Granular Matter 10.6 \(2008\)](#), p. 457-468.

2. Bubble formation in crucible

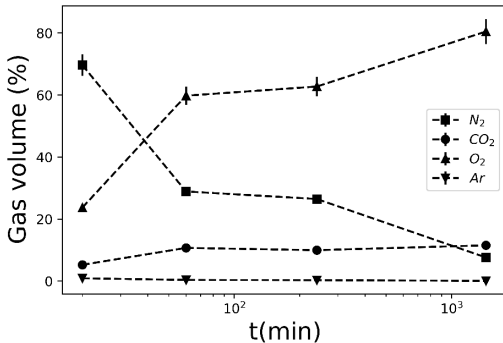


Figure 6 – Gas composition of bubble at $T = 900$ °C.

2. Bubble formation in crucible

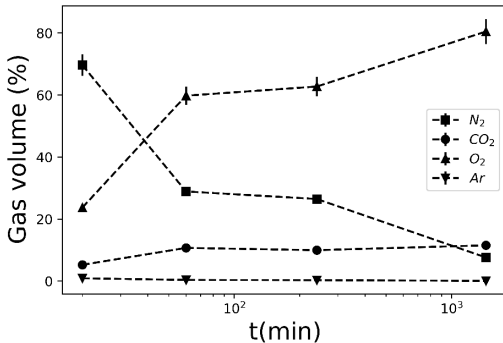


Figure 6 – Gas composition of bubble at $T = 900^\circ\text{C}$.

➔ Population of bubbles created by air entrapment.

2. Bubble formation in crucible

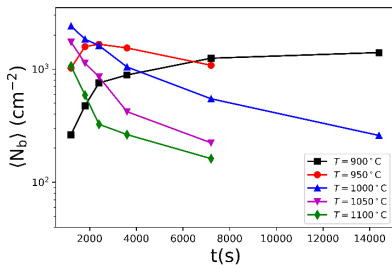


Figure 7 – N_b (cm^{-2}) vs. t .

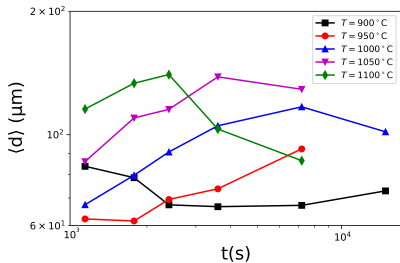


Figure 8 – $\langle D \rangle$ (μm) vs. t .

2. Bubble formation in crucible

$$t_{\eta} = \frac{H\eta(T)}{\rho g \langle D \rangle_0^2}; \quad (2)$$

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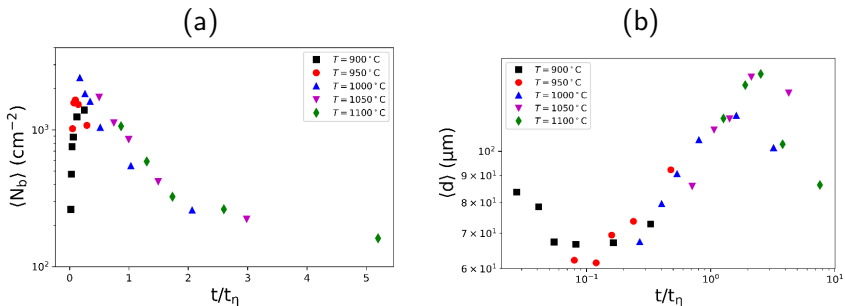


Figure 9 – (a) N_b ($/\text{cm}^2$) vs. t/t_η & (b) $\langle D \rangle$ (μm) vs. t/t_η .

3. Numerical predictions

- ▶ Development of numerical model based on a population balance equation² :

$$\frac{\partial n}{\partial t} = \quad (3)$$

2. [D. L. Marchisio/R. O. Fox](#) : Computational models for polydisperse particulate and multiphase systems, [2013](#).

3. Numerical predictions

- ▶ Development of numerical model based on a population balance equation² :

$$\frac{\partial n}{\partial t} + \frac{\partial(\dot{a}n)}{\partial a} + \sum_{i=1}^{N_g-1} \frac{\partial(\dot{\omega}_i n)}{\partial \varpi_i} = \quad (3)$$

mass transfer ;

2. Marchisio/Fox : Computational models for polydisperse particulate and multiphase systems (cf. note 2).

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mass transfer ;

bubble release from the free surface ;

2. Marchisio/Fox : Computational models for polydisperse particulate and multiphase systems (cf. note 2).

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mass transfer ;

bubble release from the free surface ;

binary coalescence due to bubble rising³ :

$$h(\mathbf{x}, t; a) = \frac{1}{2} \int_0^a \frac{a^2}{(a^3 - a'^3)^{2/3}} K(a', \sqrt[3]{a^3 - a'^3}) n(\mathbf{x}, t; a') n(\mathbf{x}, t; \sqrt[3]{a^3 - a'^3}) da' - n(\mathbf{x}, t; a') \int_0^\infty K(a, a') n(\mathbf{x}, t; a') da'. \quad (4)$$

2. Marchisio/Fox : Computational models for polydisperse particulate and multiphase systems (cf. note 2).

3. [D. Ramkrishna](#) : Population balances. Theory and application to particulate systems in engineering, [San Diego 2000](#).

3. Numerical predictions

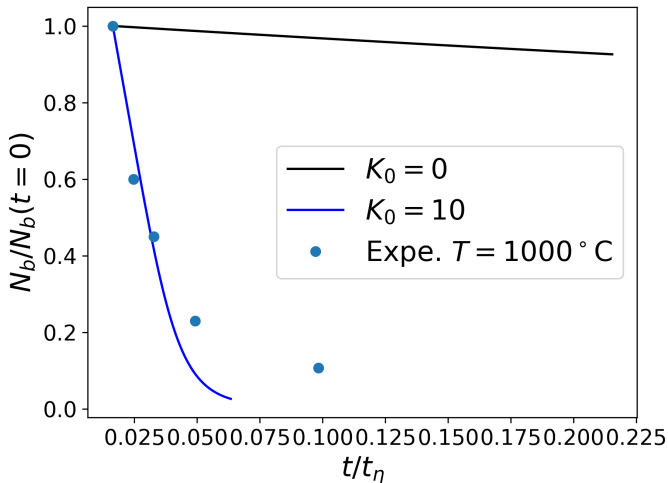


Figure 10 – $\mu_0 = N_b/N_b(0)$ vs. t/t_η with and without coalescence at $T = 1000^\circ\text{C}$.

3. Numerical predictions

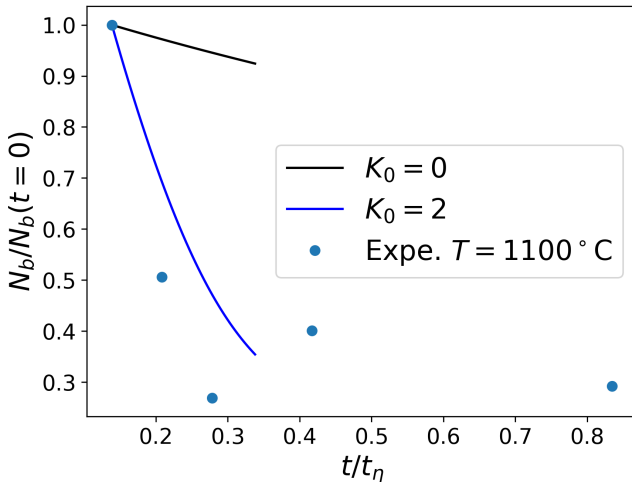


Figure 11 – $\mu_0 = N_b/N_b(0)$ vs. t/t_η with and without coalescence at $T = 1100^\circ\text{C}$.

4. Synthesis

- ▶ Initial bubbles are due to the atmosphere entrapment during the melting ;
- ▶ The size distributions are log-normal distributed ;
- ▶ The dynamics is strongly thermal activated (scaled by the viscosity) ;
- ▶ The bubble coalescence is main phenomenon at short times (confirm the assertion of Cable⁴).

4. M. Cable : A study of refining. Part 2 : Mechanisms of refining, in : *Glass Technol.* 2 (1961), p. 60-70.

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See the poster !

4. Cable : A study of refining. Part 2 : Mechanisms of refining (cf. note 4).