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Dynamics of bubble population undergoing mass transfer and coalescence in a glass forming liquid

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During the melting of raw materials, bubbles are created due to the trapping of atmospheric gases and the decomposition of mineral species used as batch components. Recent experiments achieved by Pereira et al. [1] on glass cullet melting in a small crucible confirm this assumption. The bubble dynamics can be rescaled by the residence time of a bubble in the crucible directly linked to the temperature via the dynamical viscosity. A first attempt to model the dynamics of bubble density by taking into account the bubble rising and mass transfer between the two phases failed. Cable [2] underlined that bubble coalescence can play a role in the dynamics at the early times of the process.

To rationalize the influence of mass transfer and coalescence, a population balance equation is derived to study the dynamics of bubbles in a glass forming liquid. According to the nomenclature of Hulburt and Katz [3], internal coordinates are the radius, and the $N_g - 1$ molar fractions of the N_g gas species dissolved either physically or chemically in the glass forming liquid. The coalescence kernel is determined by taking into account the velocity difference of the bubble rising in the crucible. A collision efficiency based on the dynamics of film drainage between two bubbles is also derived according to Guémas et al. [4]. The temporal behaviours of the dissolved gas are also included in the theoretical model.

A Direct Quadrature Method of Moments (DQMOM) [5] is used to solve numerically the population balance equation. In this method, the size distribution function is decomposed over N discrete Dirac distributions characterised by its weight w_α and its abscissa ξ_α with $\alpha = 1, \dots, N$. The description of the $2N$ first moments allows to determine $2N$ balance equations for the w_α and ξ_α . This system is coupled to the balance equations of $N_g - 1$ molar fractions in each discrete distribution and to the N_g molar concentrations of gas species dissolved in the liquid. The whole system is numerically solved using a Runge-Kutta method at the fourth order. Initially, the bubble size is distributed according to a log-normal distribution.

The numerical results are compared to Experimental data showing that coalescence is important at short time mainly due to the fact that the bubble population is dense. In a such case, the coalescence efficiency is relevant. When the bubble population decreases enough, coalescence events are scarce. The dynamics of the bubble is limited to the removing from the free surface of the crucible.

References

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