LETTERS TO THE EDITOR

To the Editor:

In their recent paper [*AIChE J.*, **24**, 454 (1978)], Bhavaraju, Russell, and Blanch discuss prediction of bubble properties in sparged gas-liquid contacting. Two regions are recognized. Region I is designated as the volume in the close vicinity of the sparger where bubble properties are determined by the bubble formation process. Region II is the upper portion of the tank volume where bubble properties are determined by bulk liquid motions which induce either break-up or coalescence.

In my earlier paper on scale-up of gas-liquid mass transfer in agitated vessels [*AIChE J.*, **20**, No. 3, 445 (1974)], I used the geometric mean of bubble sizes in the two regions to characterize performance. Bhavaraju, Russell, and Blanch properly point out that a weighted mean can provide better precision. They define the height of Region I to be that in which the gas jets leaving the orifices of a sparger continue to widen until they interact with other jets or the walls of the vessel. Although they apply their weighting procedure to k_La values based on bubble sizes in the two regions, direct application to obtain a characteristic mean bubble size is also useful:

$$D_{BM} = \left[\frac{H_I}{H_T}\right] D_{BO} + \left[1 - \frac{H_I}{H_T}\right] D_{BE} \quad (1)$$

H_I/H_T can be a substantial fraction in small tanks, but becomes progressively less influential with increasing tank size. The importance of this shift in scaling performance from small to large vessels is obvious.

If gas is introduced through the holes in a sparger at a low rate and then gradually increased, bubble formation goes through a progression of two phase flow regimes: single bubble formation, laminar chain bubbling, turbulent chain bubbling, transition to spouting and spouting. Bubble size determination and bounds between these regimes are covered in the literature [van Krevelen and Hoftizer, CEP, **46**, No. 1, 29 (1950): Liebson et. al., *AIChE J.*, **2**, No. 3, 296 (1956)]. In commercial practice, sparger operation is commonly in the upper turbulent chain bubbling regime.

As shown by Lehrer [*IECPDD*, **10**, No. 1, 38 (1971)], bubble size for Region I in this regime, presuming $\rho_l >> \rho_g$, is

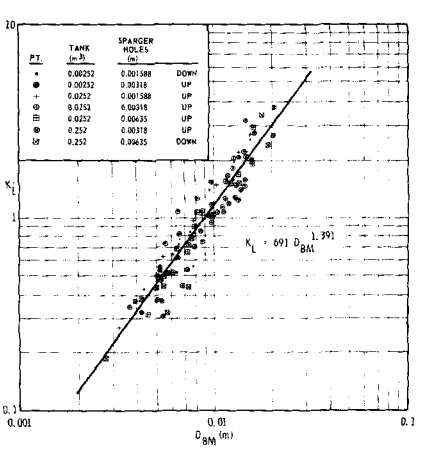
$$D_{BO} = \left(\frac{6Q}{\pi N}\right)^{0.4} \left(\frac{3C_D}{4g}\right)^{0.2} \quad (2)$$

and bubble size for Region II, for vessel depth to diameter ratios close to one, is

$$D_{BE} = \left(\frac{8\sigma}{\rho C_D}\right)^{0.6} E^{-0.4} \quad (3)$$

For simplification, the drag coefficient C_D in equations (1) and (2) is often taken equal to 2.6. A further refinement can be made in determining D_{BO} and D_{BE}, as indicated by Mendelson [*AIChE J.*, **13**, No. 12, 250 (1967)], by calculating C_D from

$$C_D = \frac{8}{3} \frac{N_{Eo}}{4 + N_{Eo}} \quad (4)$$



$$N_{Eo} = \frac{g\rho D_B^2}{4\sigma}, \quad \text{Eötvös number}$$

I have recalculated the data presented in my earlier paper based on equations (1) through (4) and results are summarized in the Figure 1 plot of k_L^* versus D_{BM}. The k_L^*'s represent experimental k_L's referred to corresponding values calculated from the Boussinesq equation:

$$N_{sh} = \frac{4}{\pi} N_{pe}^{1/2} \qquad (5)$$

As it turns out, the linear fit to Figure 1 data

$$k_L^* = 691\, D_{BM}^{1.391} \qquad (6)$$

reproduces the original fit quite closely, the square of the multiple correlation coefficient being $R_A^2 = 0.904$.

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To the Editor:

We would like to comment on a recent communication by Lee [*AIChE J.*, 24, 535 (1978)] related to the determination of size-dependent birth and growth rates of secondary nuclei in suspension crystallization systems. The author proposed an experimental method which involves the use of a single-seeded batch crystallizer with removal of the seed at $t = t_r$ (SSBCR crystallizer). The secondary nuclei generated by the seed are then allowed to grow. In his analysis, Lee considered the following population balance equation:

$$\frac{\partial}{\partial t} n(t, L) + \frac{\partial}{\partial L} G(L) n(t, L) = b_n(L; t \leq t_r, L \geq L_c) = 0 (t > t_r \text{ or } L < L_c)$$

By assuming the growth rate (G) and birth rate (b_n) to be independent of time (t), Lee was able to obtain a simple expression relating the total cumulative birth rate, and the growth rate. Lee then suggested that the size-dependent birth and growth behavior of secondary nuclei can be determined from experimental data using this simple expression.

This letter is intended to point out a basic inadequacy in Lee's approach. Lee assumed, although never stated directly in his communication, that G and b_n are independent of time (t). However, in a batch crystallizer, both G and b_n are almost always functions of t since the solution supersaturation changes throughout the entire process. Therefore, Lee's analysis cannot be applied to a practical batch crystallization system unless conditions are programmed precisely to maintain a constant supersaturation. Experimentally, this would be extremely difficult to carry out, especially for a Class II system.

On the other hand, we certainly agree with Lee's comments that the conventional CMSMPR approach cannot be used for the determination of size-dependent birth and growth behavior of secondary nuclei unless certain assumptions [Randolph and Cise, *AIChE J.*, 18, 798 (1972)] are made. A rigorous solution to this problem undoubtedly represents a challenge to people working in the crystallization field.

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Reply:

Determination of birth and growth rate of secondary nuclei involves particles of small size. In the case of a fast growing (Class II) system of $MgSO_4 \cdot 7H_2O$, the size range of interest is at most up to 70μm [Sikar and Randolph, *AIChE J.*, 22, 110 (1976); Khambaty and Larson, *I&EC Fund.*, 17, 160 (1978)]. In the experimental runs of the SSBCR crystallizer, the duration of a run and t_r can be chosen in such a manner that supersaturation is maintained constant throughout a run and yet information necessary for determining birth and growth rate of secondary nuclei can be obtained. Therefore, for a typical SSBCR run supersaturation is virtually invariant with time for all practical purposes. We illustrate this using the data of Khambaty and Larson (1978). According to their most efficient method of producing secondary nuclei by contacting, the birth rate is approximately 100 nuclei/(ml soln)(min). If we choose t_r as 2 minutes and let them grow to the size of 70μm, the number of nuclei with the size range up to 70μm would be 200 nuclei/(ml soln). The growth rate that they determined for the particles of size greater than 14μm is approximately 3.5μm/min. If all the nuclei were to be born with size of 14μm, it would take 16 minutes to reach the size, 70μm. In reality, it would take much longer than 16 minutes to reach the size of 70μm since the growth rate of nuclei with size less than 14μm is much smaller than 3.5μm/min and most of the nuclei born would have size much less than 14μm. Therefore, duration of the SSBCR run for the size distribution up to 70μm would be around 30 to 40 minutes. If we assume that all the particles reach the size of 70μm in a SSBCR run lasting 30 to 40 minutes, the maximum change in supersaturation due to crystallization can be calculated to be approximately 2.4×10^{-4}gm $MgSO_4$/ml soln. Particles were assumed to be spherical. Since the supersaturation of 3.3°C used by Khambaty and Larson (1978) corresponds to approximately 0.027 gm $MgSO_4$/gm H_2O [Sikdar and Randolph (1976)], the maximum change in supersaturation during the SSBCR run described above is less than 1%, which can be neglected. That is, supersaturation during the SSBCR run is virtually invariant with time. In another contact nucleation study involving $MgSO_4 \cdot 7H_2O$ [Lal et al., *J. of Crystal Growth*, 5, 1 (1969)], the number of nuclei born and survived was reported to be 70 nuclei/(150 cm^{3}soln)(min) with supersaturation of 3°C. Certainly, the change in supersaturation in this case can be neglected.

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ERRATA

In "Multicomponent Mass Transfer in Turbulent Flow" by Warren E. Stewart [*AIChE J.*, 19, 398 (1973)], Equation (20), $[k_x^{\vee}]$ should read $[k_x^{\vee}]$; with this change, the solution for the fluxes N_{j0} is direct, as stated.

In "Underground Coal Gasification" by D. W. Gregg and T. F. Edgar [*AIChE J.*, 24, 773 (1978)], figures 23 and 25 appeared upside down. Corrected figures appear below.

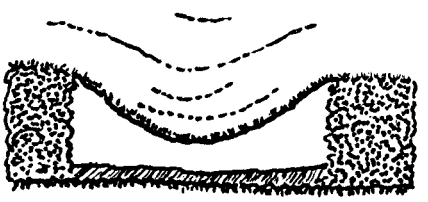

Fig. 23. Character of the filling of the gasified space due to sagging of the roof rocks.

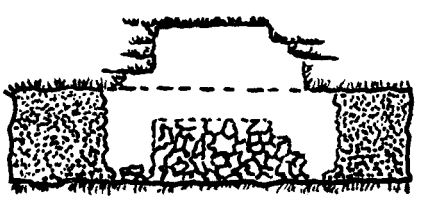

Fig. 25. Scheme of the collapse of the roof rocks into the gasified space without considerable breakdown of these rocks.