Bubbles in flow streams and porous media

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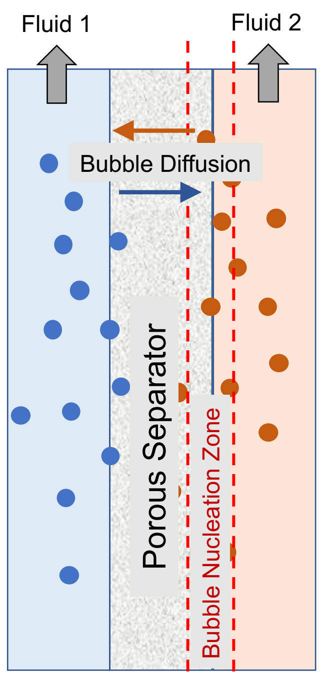
In many multi-phase chemical and electrochemical reaction systems, we have fluid streams with dissolved gas or gas bubbles that flow alongside a flat sheet of porous material [1, 2]. The pore space within this material is saturated with the fluid stream. The porous material in these situations is often thin and is a composite of materials with very different surface energies. Usually, it is desirable for the porous material to remain completely wetted by the liquid phase. Chemical/electrochemical reactions occur at the surface/interface between the porous material and fluid. We are interested in understanding the dynamics of bubble interactions and dissolved gas within the porous material. A simplified geometry describing the system is shown below.



In the diagram, there are fluid streams on both sides of the porous material. The liquid phase in both streams is usually water. The flow rate of each stream is usually different. There may be a pressure gradient across the porous material. Each fluid stream can contain dissolved gas species, dispersed gas bubbles, and dissolved ions. The concentrations of dissolved gas, gas bubbles, and ions are usually different between the two streams. The chemical composition of the dissolved gas and gas bubbles is also usually different between the two streams; that of the ions may or may not be different. The gas bubbles in each fluid stream have a wide size distribution and interact with the surface of the porous material through a variety of mechanisms:

a. Collision with the surface resulting in bouncing off or sticking.
b. Migrating along the outer surface of the porous material and/or detaching from the outer surface and/or entraining into the pore space.
c. Fragmentation or merging that creates smaller or larger bubbles, respectively.
d. Growth or shrinking of individual bubbles.

Additionally, the chemical/electrochemical reactions occurring within the system can result in supersaturation leading to nucleation of new bubbles [3, 4]. These nucleation events can occur within the bubble nucleation zone indicated in the figure. Note that each fluid channel may have a bubble nucleation zone if the fluid stream contains dissolved gas. In the figure the zone is only shown for one of the two sides.

The net effect of all these mechanisms is to cause a decrease in surface area of the porous material that is in contact with the liquid phase and crossover of bubbles and dissolved gas from one side of the porous material to the other. These are undesirable effects.

Our goal is to develop a model or set of models that will answer the following key questions:

1. How do the properties of the porous material (e.g., pore size distribution, surface energy distribution, curvatures within the pore space) influence steady state gas volume fraction in the porous material (including within its pore volume and at its two outer surfaces) as a function of depth into the porous material when subjected to a fluid stream super-saturated with dissolved gas bubbles that is flowing past it on one side and a fluid stream with no dissolved gas or bubbles on the other side? Consider three cases:

    a. Balanced pressure across the diaphragm, near ambient pressure.

    b. Balanced pressure across the diaphragm, high pressure.
    c. Pressure differential across the diaphragm, high pressure on one side and near ambient on the other.

2. What are the critical lengthscales that control bubble nucleation, growth/shrinking, and sticking/detachment from the nucleation zone?
3. If the system has two layers of porous material, each with different properties, and with bubble nucleation occurring in the layer adjacent to the flow stream, how does the steady state gas volume fraction change with depth into the porous material under the three cases described in question 1?
4. How does the system respond to a change in nucleation rate with time (e.g., step function)?

References

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