Bubble Power

There is a large difference between coarse bubbles and large bubbles in terms of how well they mix the water. Both, in terms of mixing water, work essentially the same way, at least in how water interacts with and moves about and around the bubbles. However, there are drastic differences with the size of the bubbles, and how they differently interact with water.

Velocity

1.2 Bubble Shape

Bubble shape varies with the diameter and this is caused by the varying drag forces.

Radius	< 0.01 cm	solid spheres
Radius	0.01 to 0.1 cm	deviational from spherical
Radius	> 0.1 cm	ellipsoidal

1.3 Motion and Velocity of Bubbles

The regime of bubble motion varies considerably with the Reynolds number,

$$R_e = \frac{Ua}{\gamma} \qquad (3)$$

where U = bubble rise velocity
a = bubble radius
γ = kinematic viscosity of fluid

1. For $R_e < 1$
   $a < 0.01$ cm Stokes Law Regime

$$U = \frac{1}{3}\left(\frac{ga^2}{\gamma}\right) \qquad (4)$$

where g is the gravity constant.

Bubbles rise vertically without oscillating.

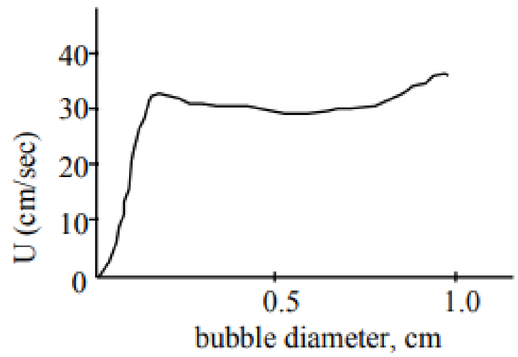
2. For $1 < R_e < 800$ which occurs for bubble radii from 0.01 cm to 0.1 cm.

$$U \sim 2\sqrt{\frac{ga}{0.9}} \qquad (5)$$

Bubbles move in a helical fashion.

3. For $R_e = 800$ and $a > 0.1$ cm

Bubbles are ellipsoidal in shape, motion is irregular, and velocity is independent of bubble diameter (U is approx. 28 - 30 cm/sec) for bubbles having radii up to 0.75 cm. For larger bubbles their velocity tends to increase to 35 - 40 cm/sec, but they are not stable and tend to subdivide into smaller bubbles.



This should give a semi-quantitative indication of the size of bubbles that are formed and the rise velocity as a function of size. Unfortunately the number of bubbles expelled as a function of gas flow rate cannot be quantitatively described, and empirical methods must be utilized.

http://www.seas.ucla.edu/stenstro/Bubble.pdf

Here you can see that coarse bubbles will move through the water with a velocity on the range of 30-40 cm, or 1-1.3 ft/s.

The large bubble created by the bubble accumulators rise at approximately ~130cm/s or ~4ft/s, which can be shown in video. The velocity of the bubble adds extensively more power into the water column. The difference is, there will be many more coarse bubbles continuously rising at the equivalent air flow rate, but all rising at the same velocity.

Displacement

Each bubble as it rises displaces water around it, which makes a high pressure zone on top of the bubble, and a low pressure zone on the bottom of the bubble, with eddy currents caused by the drag to the sides of the bubble. The way water is mixed by bubbles is by getting entrained behind a bubble, essentially due to the induced vacuum caused by the bubble displacement and induced low pressure zone behind it. The larger the bubble and the faster that it rises, the more powerful the induced vacuum, therefore the more water that it can move. This can be somewhat thought of as an unconstrained airlift pump, where the bubble essentially pushes water up (like an air piston) and out of the way to the side and pulls water up from below, even pulling more dense water and solids. If the bubbles were constrained to a pipe, for example, water would be forced up and out and pulled up through the pipe. The most efficicent way to pump through a pipe like this is with a slug bubble intermittently, i.e. a large bubble. (Betrand de Azevedo, et al, 2012). With both of these phenomena in mind, it leads to how much energy is transferred to the water for mixing? This is extremely difficult to model computationally, since bubbles rise as amorphous masses once they get very large – they are not a single bubble, but a slug of large (6-8") smaller bubbles all rising together. However, there are formulas that have been proposed, and what it comes down to is that the power transferred to the water increases on the cubic to the relative size of said bubble. That is, one 1cm3 bubble has a power of 1, but a 40 L bubble has a power not 4000x, but 4000^3 (64 billion) times more powerful than a single bubble of $1cm^3$ for mixing. Obviously then, to compare, one would need to provide an equivalent number of bubbles, for the same volume, so 4000 $1cm^3$ bubbles, which would still only have 1/16 millionth the mixing power of a single large bubble. So for adequate mixing, a coarse bubble aeration system will take massively more power (air flow, KW/hr, HP) to do the same mixing as a large bubble system.

<u>Agitation Potential of Large Bubbles for Mixing Applications</u>

Energy is a key metric to evaluate the capability of bubbles to provide agitation in wastewater basins (essentially mixing). Assuming constant pressure at a depth below the surface of the water, the energy to create a bubble is;

$$E = \int_0^R P dV = \int_0^R P(4\pi r^2 dr) = P\int_0^R 4\pi r^2 dr = P\left(\frac{4\pi R^3}{3}\right)$$

Assuming the bubble (a) gently breaks the water surface when it rises to the surface, (b) has a negligible increase in volume during the rise, i.e., a few feet below the surface, and (c) has lost a negligible amount in viscous friction, then the energy used in creating that bubble has been transferred to kinetic energy during the rise. In large bubbles, most of this energy will be in the form of moving the water and contents rather than viscous heating. Note that the energy available to a specific bubble is proportional to cube of the bubble radius.

If smaller bubbles are used, where F is the radius ratio (R_{large}/R_{small}), requires that $N=F^3$ bubbles are used to achieve the same gas volume. The surface area ratio (SAR) of smaller bubbles of equal total gas volume is;

$$SAR = \frac{N(4\pi R_{small}^2)}{(4\pi R_{large}^2)} = F$$

Hence, as the small bubble's radius decreases, the surface area and the viscous friction energy dissipation increase proportional to the radius ratio. The viscous energy loss manifests itself in local heating of the water and does little for agitation and mixing. As a result, smaller bubbles have a smaller rise velocity.

The net result is that there is a clear advantage of using large bubbles for large scale agitation and mixing in wastewater applications.

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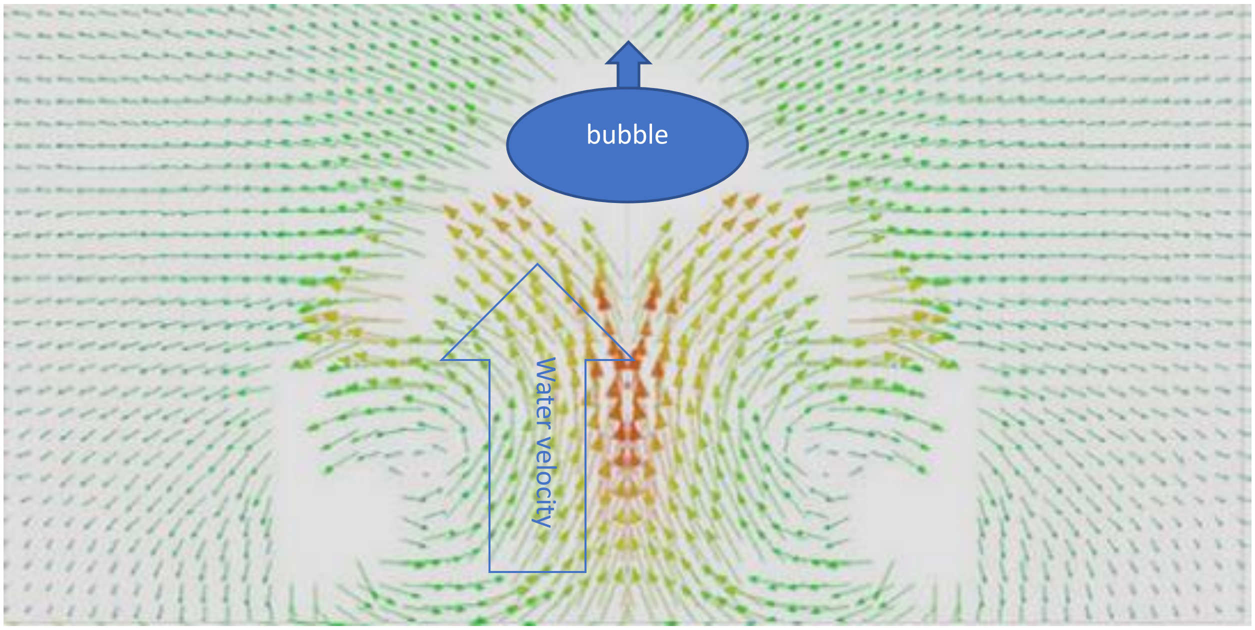
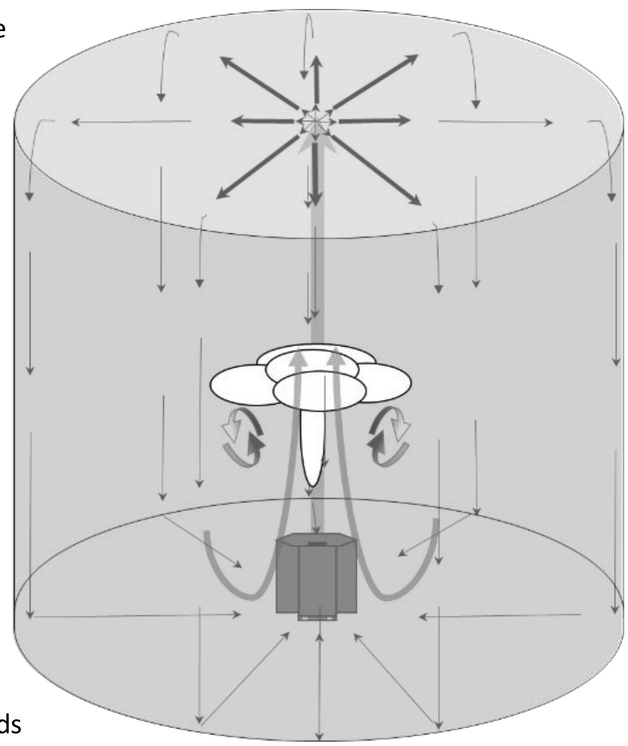
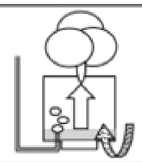
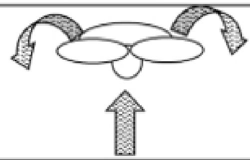
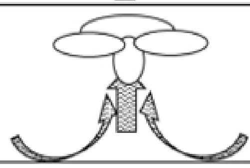
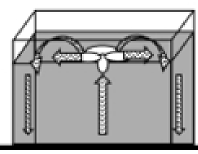




This is not the whole story, as there are other effects that take place. For example, the large bubble does have a limit to its area of effect. This will ultimately depend mostly on depth that the bubble is released and effects such as walls and 'false walls'. When a large bubble breaches the surface, the energy of that bubble has nowhere to go but up or out. Since water cannot fly, the energy is converted into lateral wake, with several seconds of upwelling behind the bubble of large volumes of water. The wake of the bubble and flow moves radially outward in a plume until the power eventually dissipates with Brownian motion and counter currents stop it, or it hits a wall. If the bubble hits a wall, or another bubble's wake (false wall), the velocity of the water has no choice but to flow downward. This essentially means that when the current induced by the bubble flows downward at a wall, vertical convection currents are induced in a tank. What is shown to happen is that the currents will flow around the tank walls and return to the bubble formation point. This motion effectively scours the bottom of the tank and forces solids to be kept moving off of the bottom of the tank. In stark contrast, with coarse bubble aeration methods, the bubbles will have very little effect of moving solids from the very bottom of the tank, especially if the orifaces are placed above the very bottom or the tank, which can result in septic zones.

What is particularly interesting with these currents, is that they tend to flow at a higher velocity than the rising velocity of fine bubbles used for aeration – this can effectively raise the SOTE in an aeration zone by effectively adding extra depth to the tank, as the fine bubbles can be in contact longer with the water column (there are videos and data available to show this phenomena).

	**Burst** When the critical point is reached, an air siphon forms and draws the accumulated volume of air out of the ejection port. This draws water and solids into the accumulator. The dual action siphon draws water from the bottom of the mixer through the exhaust with the air as it is released.
	**Rising Bubble** As the bubble begins to rise through the water column, it forms a flat mushroom shape, displacing large amounts of water from the top of the bubble. The large volume of air rises with much higher velocity than smaller bubbles. The water pumped through the mixer as the bubble is released is also forcefully risen
	**Vacuum** In the wake of the rising bubble, a vacuum is formed, drawing liquids and solids with it. This action causes solids to be drawn to the surface.
	**Wake** When the bubble breaks the surface, energy must be dispersed outward as small waves, carrying water and solids particles outwards from the breach zone. This action induces large convection like currents in the water column. The currents move water from the surface back down to bottom of the tank.

In flocculation zones, the large bubble mixing regime is ideal for generating large rolling flocs. The large eddy currents formed by the large bubble and currents induced, provide high collision potential and also locally high shear environments which will roll and cause denser flocs to form, high current areas promoting collisions, and low velocity areas encouraging floc formation and coalescence.

Additionally, coagulants/flocculants can be added directly into each of the bubble generators, by means of a dosing pump. Upon each bubble burst, flocculant can be dispersed immediately into the water column, with ideal conditions for flocculation to occur.