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When do bubbles cause a floating body to sink?

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When Do Bubbles Cause a Floating Body to Sink?

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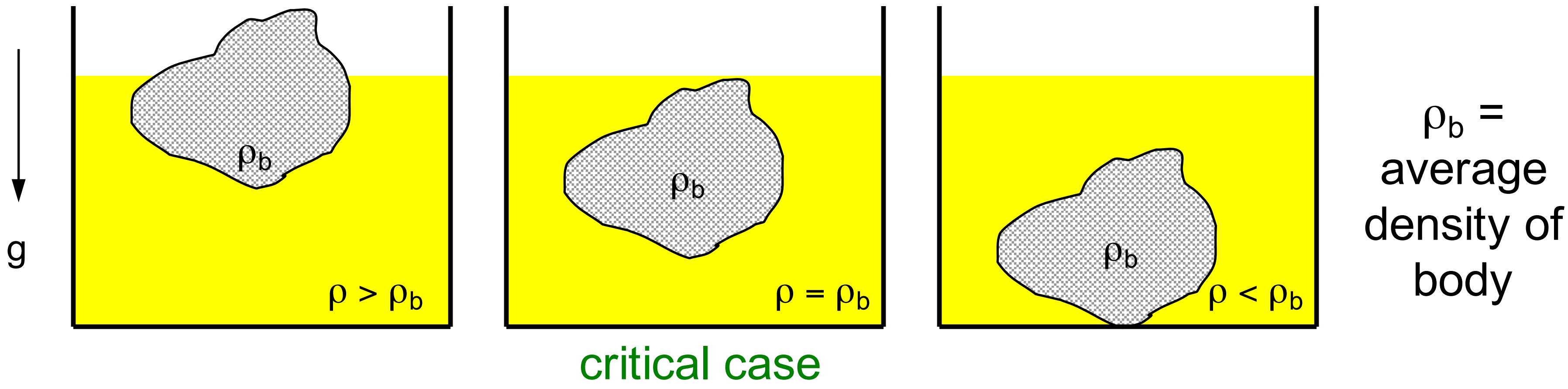
Archimedes' principle implies body will sink if $\rho < \rho_b$.
(Exception: canoe-shaped bodies)



Is this true for liquid with small rising bubbles, where ρ is average density of the bubbly liquid? Possible effects:

<u>upward forces</u>

- drag of entrained liquid
- bubble drag, impact, sticking
- surface tension

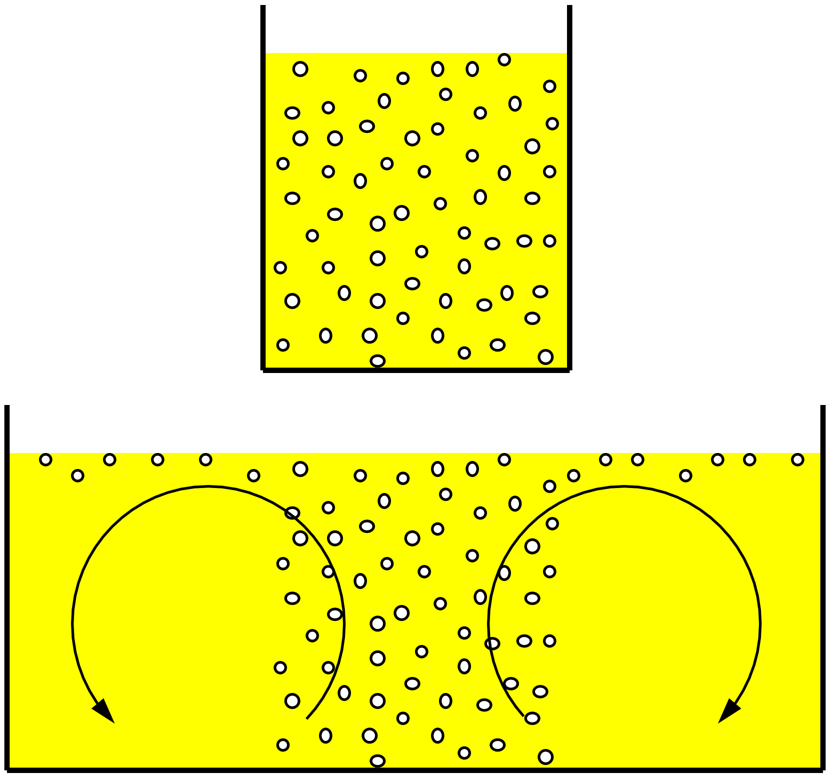
<u>downward forces</u>

- shadow region
- layer of extra bubbles
- Bernoulli effect

Upward drag increases as gas flow is increased, so sinking is not guaranteed, or critical condition may differ from $\rho = \rho_b$.

Sinking suggested as cause of demise of some ships due to methane gas from ocean floor (McIver, 1982). “Buoyancy bomb” has also been suggested (Stumborg, 2000).

Two limiting cases:



- Uniform bubbles in *closed environment*. Entrainment of liquid, and thus upward drag on body, may be negligible.

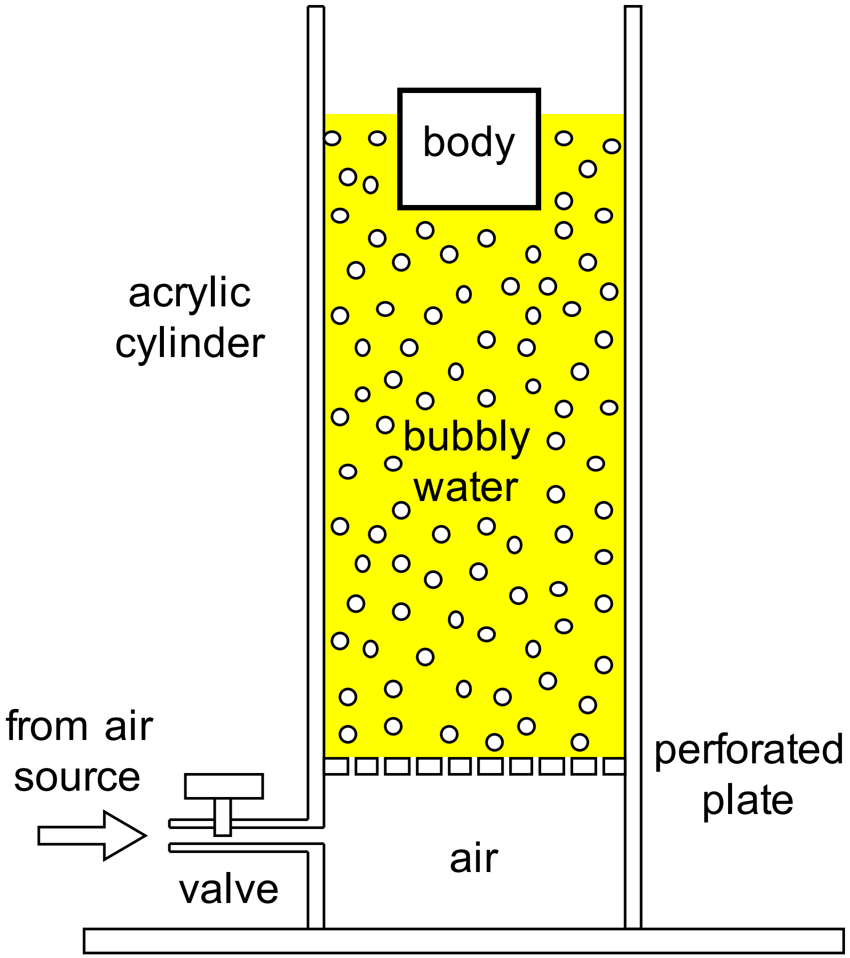
- Bubbles in *open environment*. Due to circulatory flow, upward drag expected to be significant.

Demonstrations

Sinking a floating body with bubbles in a closed environment can be demonstrated in several ways.

One involves acrylic cylinder with bubbler plate. Air can be supplied by mouth, sinking weighted bottle with specific gravity 0.96.

Ice (specific gravity 0.92) can also be sunk with apparatus.

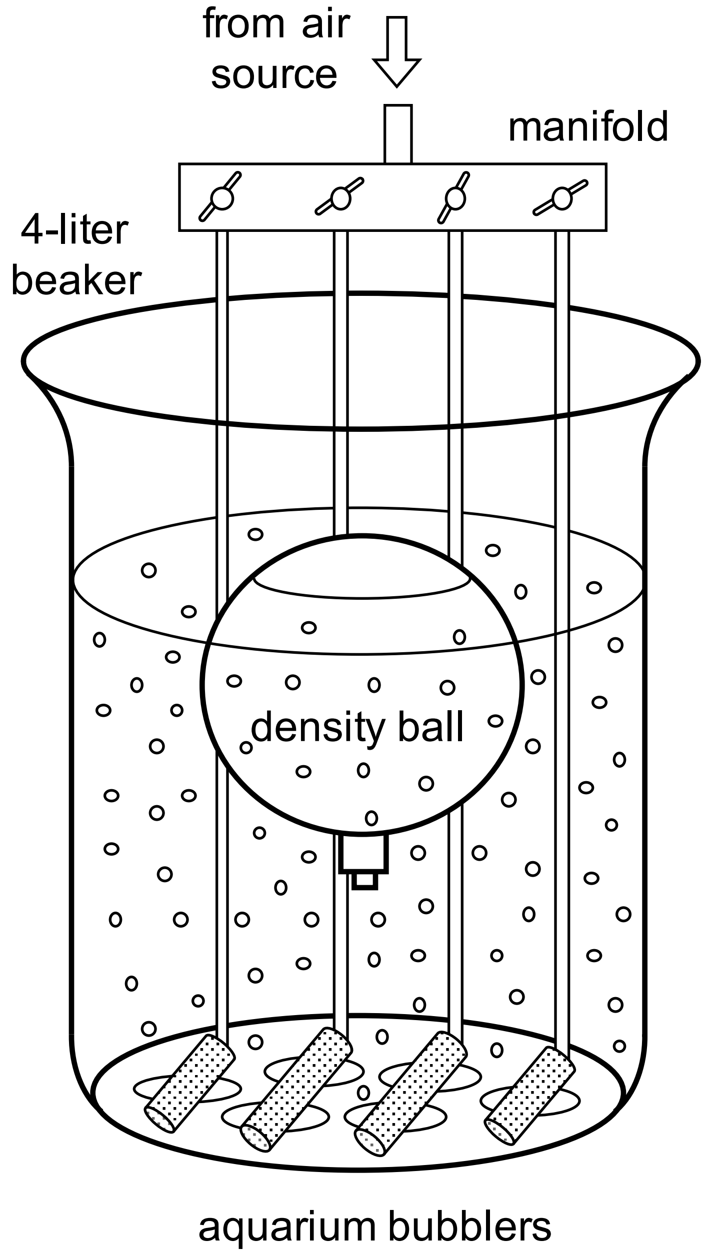


More-controlled apparatus: aquarium bubblers and commercially available 10-cm diameter “density ball.”

(Stated purpose of density ball is to float in cold water and sink in hot water.)

Manifold is necessary to obtain roughly uniform bubble flow.

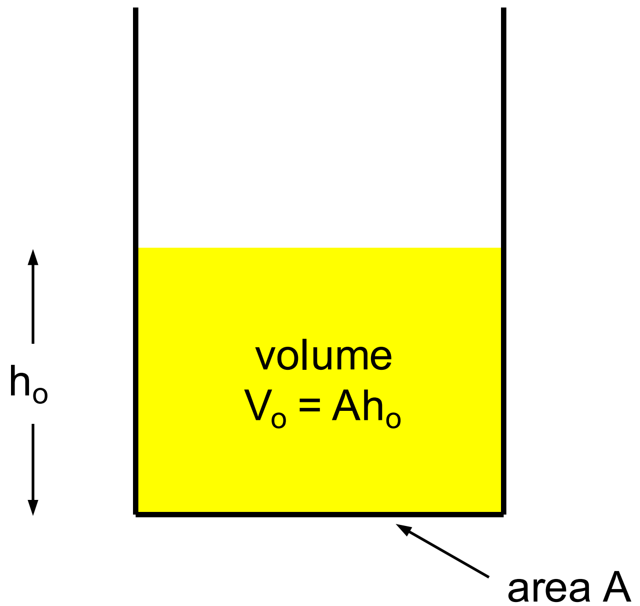
Little turbulence for ball with specific gravity 0.98, and visible in large lecture hall.



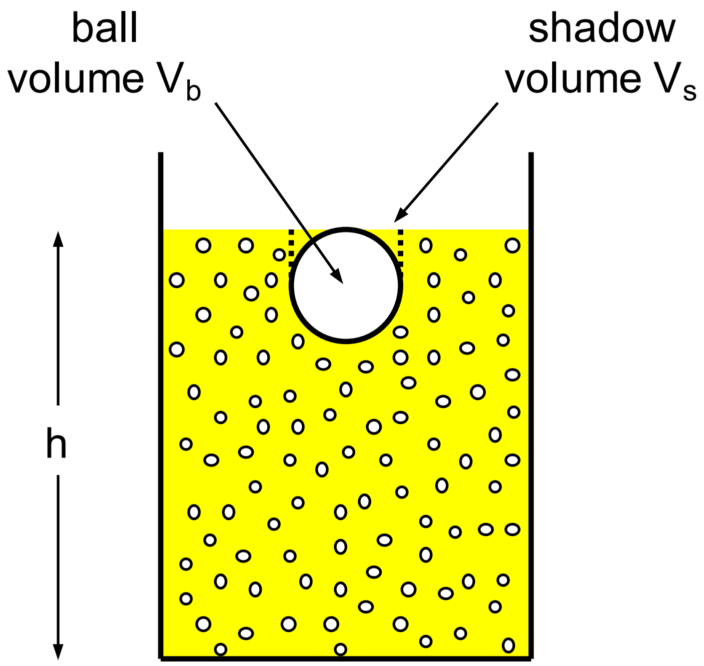
Theory

Spherical body in uniform bubble field, except for vertical shadow. (Neglect possible layer of extra bubbles.)

reference state:



critical state:



Quasistatic approximation. (Neglect possible upward drag due to liquid and bubbles, and possible Bernoulli force.)

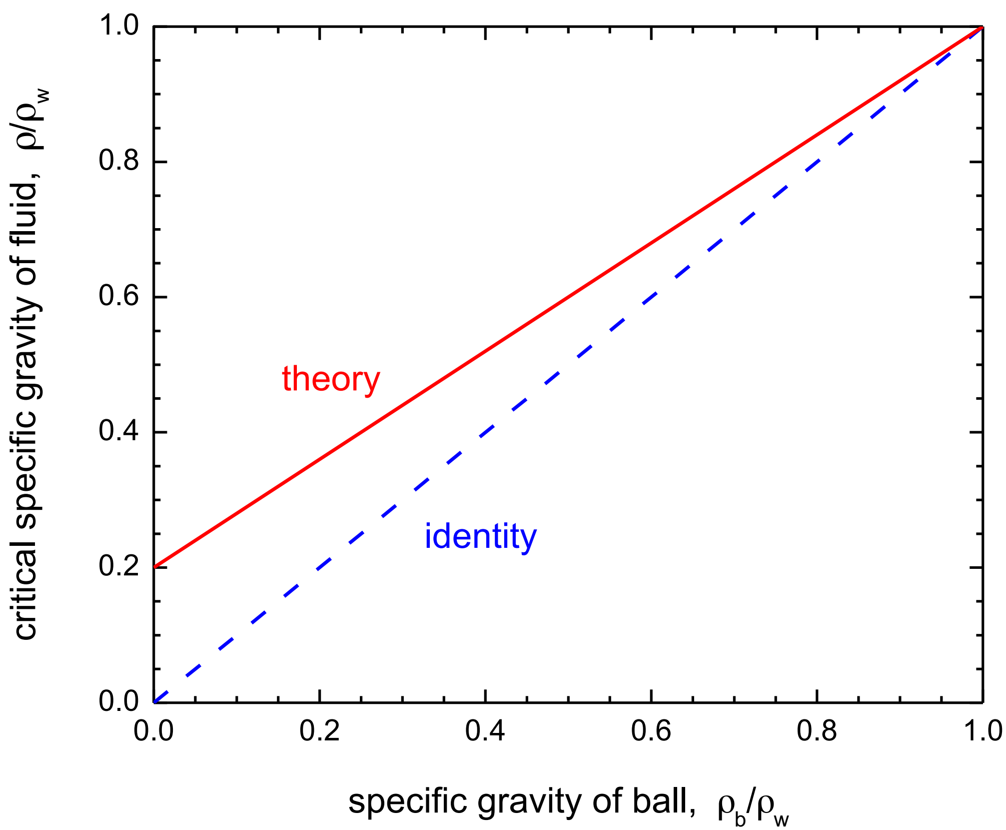
Theoretical critical density from Archimedes' principle:

$$\rho = \frac{\rho_b V_b + \rho_w V_s}{V_b + V_s}$$

Special case: $V_s = 0 \Rightarrow \rho = \rho_b$

Spherical body

($V_b = 4\pi R^3/3$
and
$V_s = \pi R^3/3$)



Average density of bubbly liquid in terms of measurable quantities is also needed.

Density in absence of ball:

$$\rho = \frac{h_o}{h}\rho_w$$

Critical density:

$$\rho = \frac{1 - V_s/V_o}{h/h_o - (V_b + V_s)/V_o}\rho_w$$

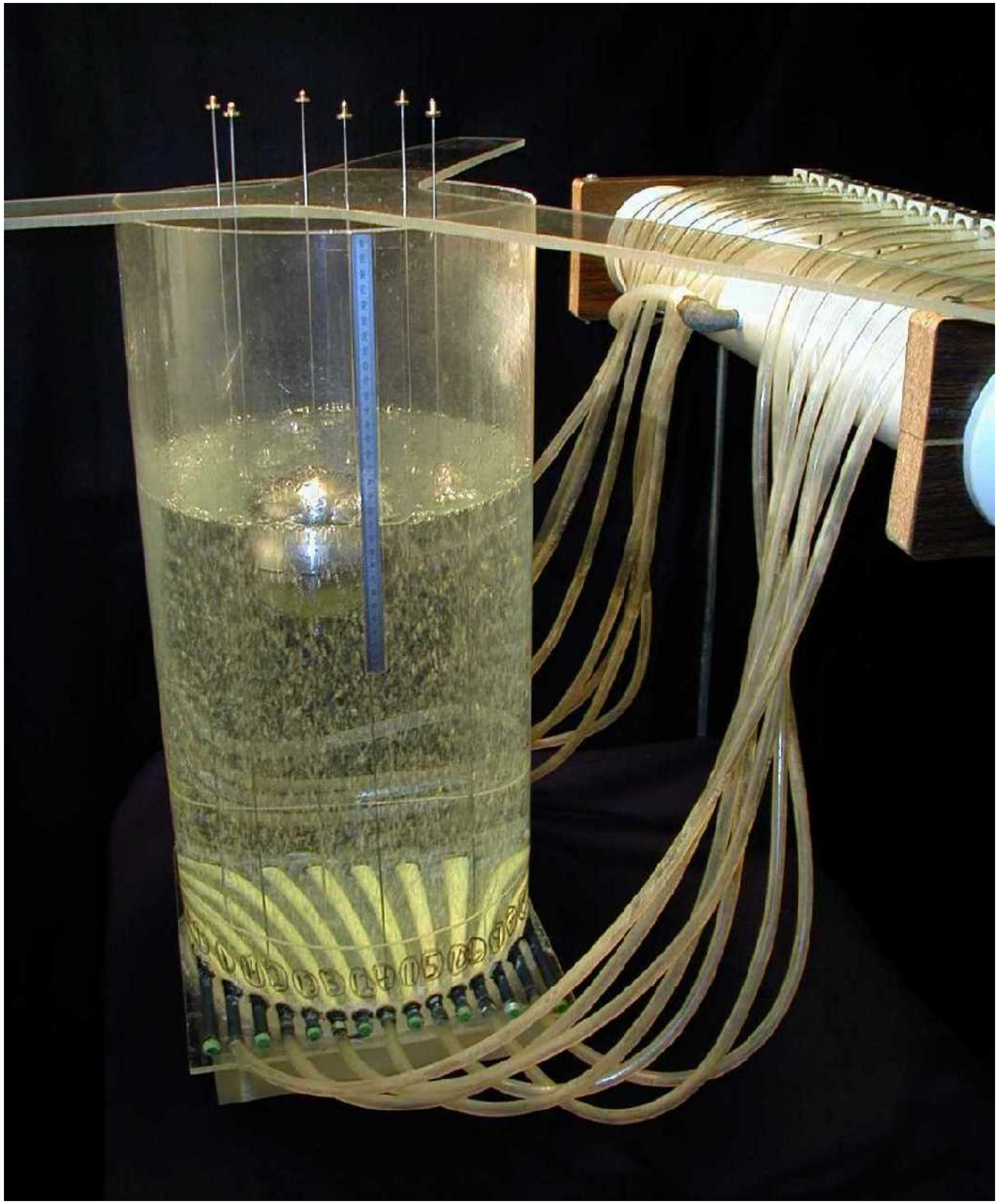
(small correction to $\rho = h_o\rho_w/h$)

Experimental Apparatus

Density ball and 15 aquarium bubblers in acrylic tube

Other components:

- 30-cm steel rule
- hexagonal cage
- leveling base
- manifold with individual multiturn needle valves



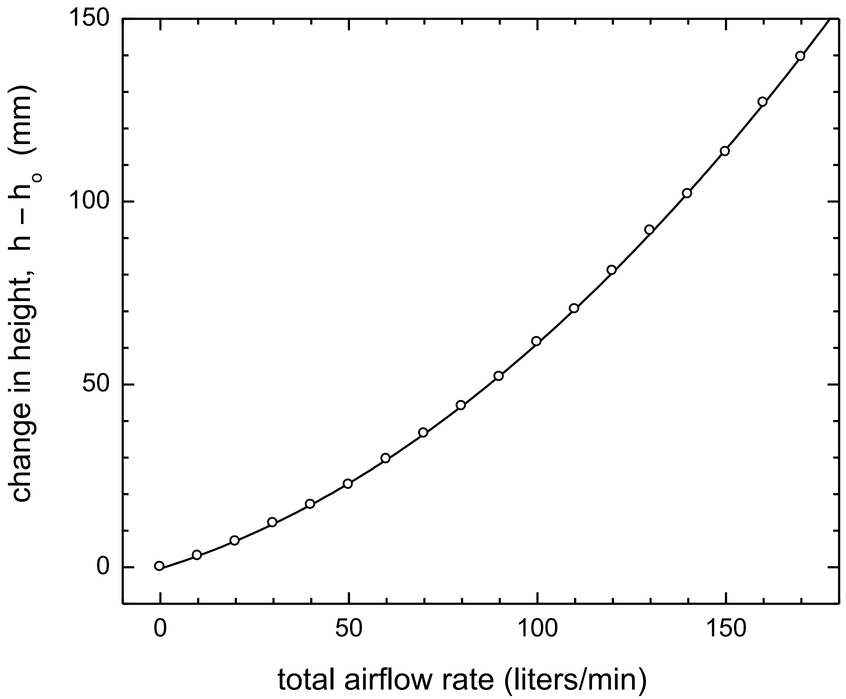
Critical to experiment is “balancing” bubble flow, so that uniform bubble field occurs. Otherwise, localized flow regions occur. Result:

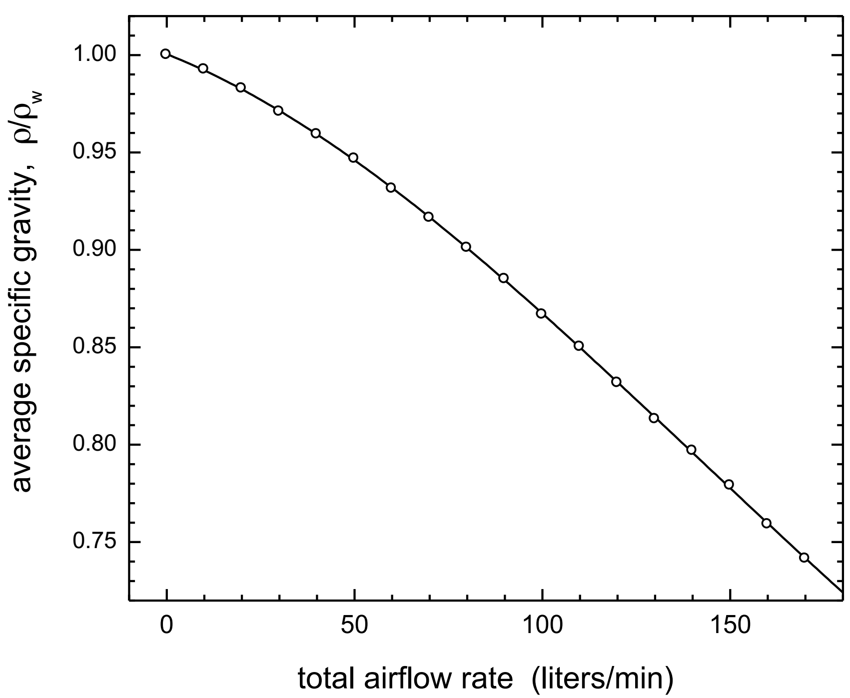
- Body can drift to region of downward flow and sink at greater average fluid density than when system is balanced.

- Fluctuations prevent precise reading of surface height.

Experimental Results

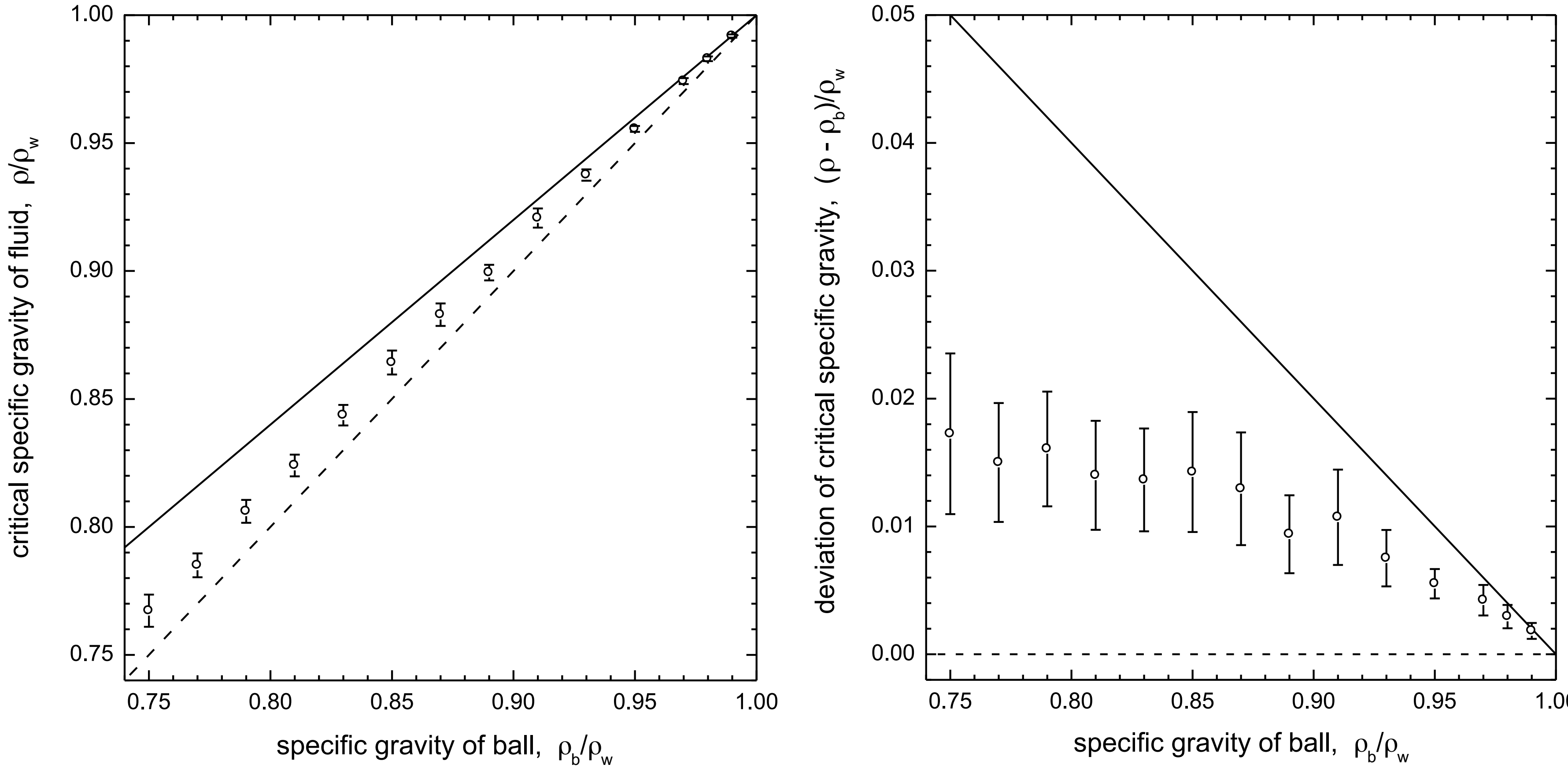
No ball:





Height of fluid column varies nonlinearly with airflow rate, because bubbles remain in tank for longer time due to height increase.

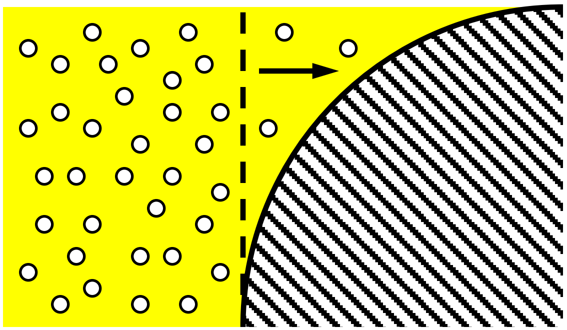
Specific gravity of bubbly water to nearly and barely sink ball:



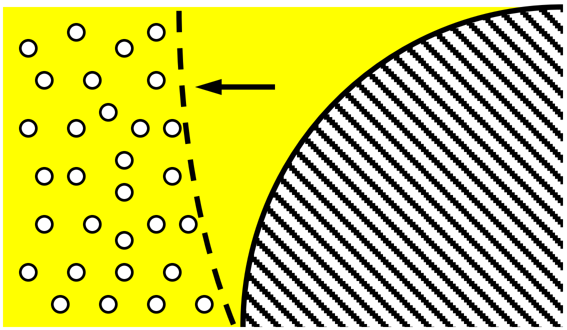
Good agreement between theory and experiment for low airflow rates, where shadow is known. Drag and other effects are evidently negligible.

Possible explanation for deviation at greater airflow rates:

Turbulence causes bubbles to effectively reduce volume of shadow region.



Competes with quasistatic pressure, which causes shadow region to expand.



Upward drag and bubble forces may also contribute to deviation.

Summary

Floating body might be expected to sink when density of bubbly liquid is less than average density of body. However, shadow region increases critical density (fewer bubbles).

Many dynamic effects could alter quasistatic critical density, especially upward drag due to entrained liquid.

Lecture demonstrations exist for sinking with bubbles in closed environment.

Experiment with carefully balanced flow in closed environment yields agreement with theory for low airflow rates, so upward drag and other effects are negligible.

At greater airflow rates, more bubbles compared to theory are required. Simplest explanation is turbulence causing bubbles to enter shadow region.

Future Work

Our work is only a first step toward answering question.

Experiments:

- Flat-top body such that no shadow exists while body is floating

- Smaller bubbles, which may increase range of agreement

- Open environment, where upward drag due to liquid is expected to be significant

Computational fluid dynamics has progressed to point where simulations may be possible.