Do the Bubbles in a Glass of Guinness Beer Go Up or Down?

Since time immemorial, mankind has been troubled by natural phenomena that cannot be easily explained. Why do the bubbles in a glass of that venerable dark brew called Guinness appear to travel downward in the glass? This goes against what we know about the physics of bubbles, or does it? The answer to this most fundamental question has been locked away for centuries, resisting the direct assault of the most determined philosophers and theoreticians without compassion. But, with the help of CFD, we can provide a categorical and definitive answer: the bubbles go both up and down.

The answer is paradoxical at first sight. Everyone familiar with hydrostatics, and having even a passing acquaintance with Archimedes, knows that gas bubbles are lighter than liquid and must experience a buoyancy force driving them ever upwards until they break out of their liquid prison and are finally liberated.

Flow pathlines in a glass of Guinness.

But what would George Stokes, the Irish mathematician and co-originator of the Navier-Stokes equations, say? It is suspected that George Stokes, and many scientists since, have given quite a few glasses of Guinness considerable intellectual attention to establish the details of this most complex of motions. It has been reported occasionally that bubbles were observed to move, surreptitiously and deviously, downwards. However, comparing the credibility of Archimedes with the authors of such doubtful observation, who is one to believe?

We must consider the viscosity, density, and temperature of Guinness, the size and shape of the bubbles. Do 20 micron bubbles behave differently from 1 mm bubbles? Is the shape of the glass important? Yes, all of these factors and many others have a role to play. We have brought together expert fluid mechanicians from around the world and used FLUENT to solve one of life's last remaining mysteries.

So what does a CFD simulation of bubble movement in a glass of Guinness show us? First, at the bottom of the glass, bubbles of all sizes naturally want to rise. So Archimedes was right after all?

Well... maybe.

In moving up, the bubbles tend to drag the liquid with them, such that the liquid also wants to move up. But certain bubbles move up more quickly than others, especially the ones away from the boundary layer near the glass wall, and liquid in the middle of the glass therefore gets dragged up more quickly. However, fundamental laws of physics dictate that the overall mass of the liquid in the glass must be conserved. Hence, the liquid moving up in the center of the glass must eventually turn towards the walls of the glass and start to move downwards in order to conserve mass. This vortex of recirculating liquid has a vital role to play in arriving at the answer to the ultimate question.

Once the liquid is moving downwards near the glass wall, the liquid motion tries to drag bubbles rising in this region down with it. Large bubbles have sufficient buoyancy (strong believers in Archimedes) to resist this deviant behavior. They move closer to the wall, but eventually escape from the surface of the liquid. However, bubbles smaller than about 0.05 mm diameter cannot resist the downward drag force, and do indeed move downwards close to the wall. So the ultimate question is answered; large bubbles rise up but small bubbles are dragged down near the side wall of the glass, which is the only part of the beer visible to the human eye.

Every worthwhile story needs a human interest element. If George Stokes was alive today would he be a CFD practitioner ? Probably, according to Nick Stokes, his great-great-grandson. It so happens that Nick Stokes is a Principal Research Scientist with CSIRO, Division of Mathematics and Information Sciences, Melbourne, Australia, and a world-recognized CFD expert. So CFD not only answers the ultimate question, but it also has all the right connections.

Bubble tracks show that the 1 mm bubbles (yellow) move steadily upwards while the 60 micron bubbles (red) are dragged downwards near the side of the glass.

Credit for this imaginative and dedicated work, supported by hours of effort in pubs and bars researching this phenomenon, goes to Professor Fletcher and students, CANCES-UNSW, Australia. We thank Guinness for providing product photography and moral support.