Fluid dynamics

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Contaminated bubble bursting

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Oil-coated bubbles bursting across interfaces enhance aerosol formation and transmission by producing jets that are smaller and faster than those formed by pristine bubbles.

Aerosols are liquid drops or solid particles that are sufficiently small and lightweight to avoid gravitational sedimentation and remain suspended in air. Bubbles bursting from liquids is one source of liquid aerosol generation. Usually, bubble bursting from water is not thought to contribute significantly to airborne transmission because of the large size of generated drops. Now writing in *Nature Physics*, Zhengyu Yang and colleagues showed that bubbles coated with an insoluble oil burst into unusually fast and small drops that may contribute to aerosolization and airborne transmission[1].

Examples of potential aerosol sources include oceans, wastewater treatment plants, carbonated beverages, boiling liquids and many industrial reactors. Although aerosols produced by bubbles bursting in our drinks or in our kettles are not a concern, aerosols originating from industrial and natural sources can have a range of detrimental effects to the built environment, the natural environment and to human health[2]. Salty aerosols originating from ocean water are responsible for corrosion of vehicles, buildings and other infrastructure located in coastal regions. Artifacts and historical structures of cultural significance, such as the Necropolis of Anfushi in Egypt and the Shore Temple in India, also suffer from salt-intrusion damage from aerosols generated by ocean water[3].

Perfluoroalkyl acids within oceans are transmitted into the atmosphere by sea spray-generated aerosols[4]. The chemical persists in the environment leading to both atmospheric pollution and to health risks for people breathing the contamination. Bacteria with sufficiently hydrophobic cell walls can adhere to the surface of a rising bubble, allowing the microorganisms to be ejected and aerosolized upon bubble rupture[2]. Thus, bubbles bursting from water sources containing bacteria provide a potential route for airborne spread of disease. Such a mechanism may be particularly important in wastewater treatment facilities, where significant levels of bacteria are detected even at sampling heights of three metres above reaction tanks[5].

Because of the importance of aerosols in the transmission of fluids, chemicals and bacteria from bulk liquid, the physics of bubble-induced aerosol generation have been subject to numerous investigations. Drop ejection speed, size of ejected drops, number of ejected drops, and ejection height are all important parameters for understanding airborne transmission and transport of aerosols. These parameters are controlled by variables including the bubble volume, bubble speed, bubble stability and the distance that bubbles travel through the liquid before bursting.

Smaller bubbles generally produce a higher number of jetting drops, yet the maximum ejection height also decreases with decreasing bubble size. Bubble stability, measured by the time spent at the air/water interface before rupture, can be tuned by the presence of salts, bacteria, and surfactants. Bubbles stabilized in such a way tend to rupture at greater velocities due to thinning of the fluid prior to rupture.

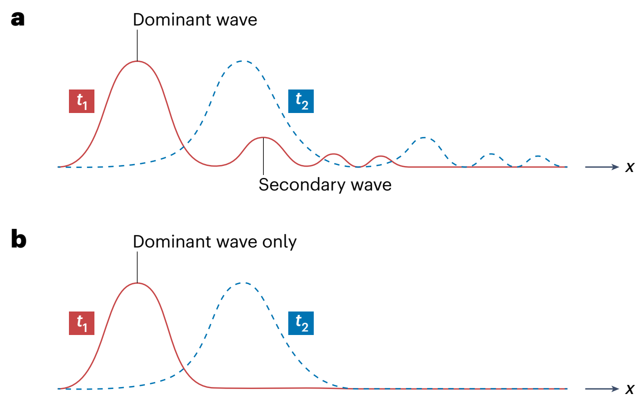

Fig. 1 | Self-similar wave propagation dynamics. a, Propagation of a wave train with secondary waves in a clean bubble. The secondary waves travel faster than the larger, dominant wave so the height profile of the waves at different times (that is, t_1 and t_2) evolves as the wave train moves in the *x*-direction. **b**, Propagation of a wave train with only the dominant wave in an oil-contaminated bubble. There is only a single wave so the height profile remains constant in time when rescaled to the position in the *x*-direction. This property is known as self-similarity.

Although previous work has explored the physics of aerosol generation from bursting bubbles, real systems are not ideal solutions of pure water or even of water with a single chemical component such as a salt or surfactant. Both ocean water and wastewater contain a myriad of contaminants including oils, dissolved minerals, bacteria and significant amounts of organic matter. Previous work exploring bubbles bursting through films of oil at the air/water interface found that the presence of oil leads to alterations in jet radius and velocity[6].

Yang and colleagues explored the influence of an oil coating that directly contaminates the surface of a rising bubble and showed that oil contamination can enhance ejection velocity by an order of magnitude compared to clean bubbles. In addition, drops ejected from oil-coated bubbles were significantly smaller than those produced by clean bubbles, leading to increased risk of aerosolization and airborne transmission.

When clean bubbles burst, multiple sets of capillary waves appear, including dominant waves and secondary waves (Fig. 1a). Secondary waves are precursor waves that travel faster, have smaller wavelengths and are less energetic than the most energetic dominant wave at the end of a train of capillary waves. The difference in propagation velocities between the waves causes the height profile of the waves to evolve in time. The team showed that when oil-contaminated bubbles burst, oil-induced viscous dissipation led to the dampening of secondary waves, which in turn allowed for self-similarity of the dominating wave height profile (Fig. 1b).

Self-similar profiles remain constant when rescaled by a variable that depends on both time and space. The self-similar focusing of two colliding dominant waves during bubble rupture is what enabled the formation of the exceptionally fast singular jet for oil-contaminated bubbles (Fig. 1b). This contrasts with the oil-free interface case (Fig. 1a), where precursor waves moving at disparate velocities allow for energetic dissipation prior to the collision of the dominant waves. The experiments by Yang and colleagues also exhibited a transition from non-singular jets to singular jetting with increasing oil viscosity. However, above a critical threshold, higher viscosities caused sufficient dampening that even the dominant wave was smoothed out and no jetting occurred.

The finding that aerosolization can occur in a context in which it wasn't previously thought possible may prove critical to understanding disease transmission from contaminated water sources. Not only did the jets move faster, but smaller drops could more easily diffuse and be picked up by currents.

The chemical composition of a water source in a real environment is more complex than the idealized oil-coated bubble in a deionized water system investigated by Yang and colleagues. For example, water salinity is known to alter bubble rupture dynamics because of salt-induced stabilization of the air–water interface. Given the key role of salt in aerosol-induced structural damage and corrosion, future work could explore the combined effects of salt and oil on bubble bursting and jetting.

Similarly, accumulation of hydrophobic micro-organisms as a function of bubble rise depth could be explored with and without the presence of an oil coating. Bacterial contamination at bubble interfaces leads to smaller and faster droplets compared to pristine interfaces due to delayed rupture caused by bacteria-induced stabilization of the interface[7]. It is possible that oil-coated bubbles could prevent bacteria accumulation at the interface and thereby decrease bacterial transmission; or that singular jets could launch bacteria within the oil phase to even greater heights than previously observed for either effect individually.

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Competing interests

The author declares no competing interests.