

Dual residence time for droplet to coalesce with liquid surface

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ABSTRACT

When approaching a liquid surface, droplets have a tendency to merge in order to minimize the surface energy. However, they can exhibit a phenomenon called coalescence delay in most cases that keeps them floating for tens of milliseconds. The duration is known as the residence time or the non-coalescence time. Surprisingly, under identical parameters and initial conditions, the residence time for water droplets is not a constant value but exhibits dual peaks in its distribution. In this poster, we present the observation of the dual residence times through rigorous statistical analysis and investigate the quantitative variations in residence time by manipulating parameters such as the droplet height, radius, and viscosity. Theoretical models and physical arguments are provided to explain their effects, particularly why a large viscosity or/and a small radius is detrimental to the appearance of the longer residence time peak.

Experimental Set-up

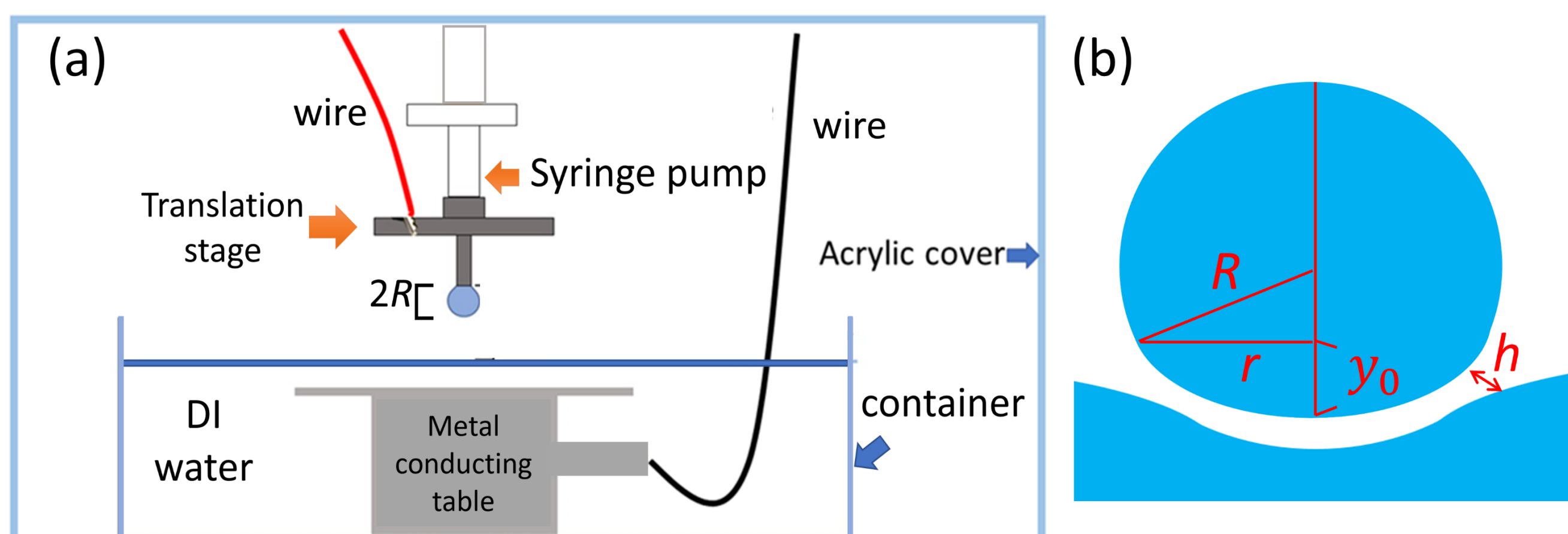


FIG. 1. (a) Schematic experimental setup for measuring the residence time of water droplets falling on a water pool through the air, (b) Cutaway view of droplet floating on the pool surface with the equilibrium depth y_0 , the radius of contact area r , and film thickness h .

Experimental Results

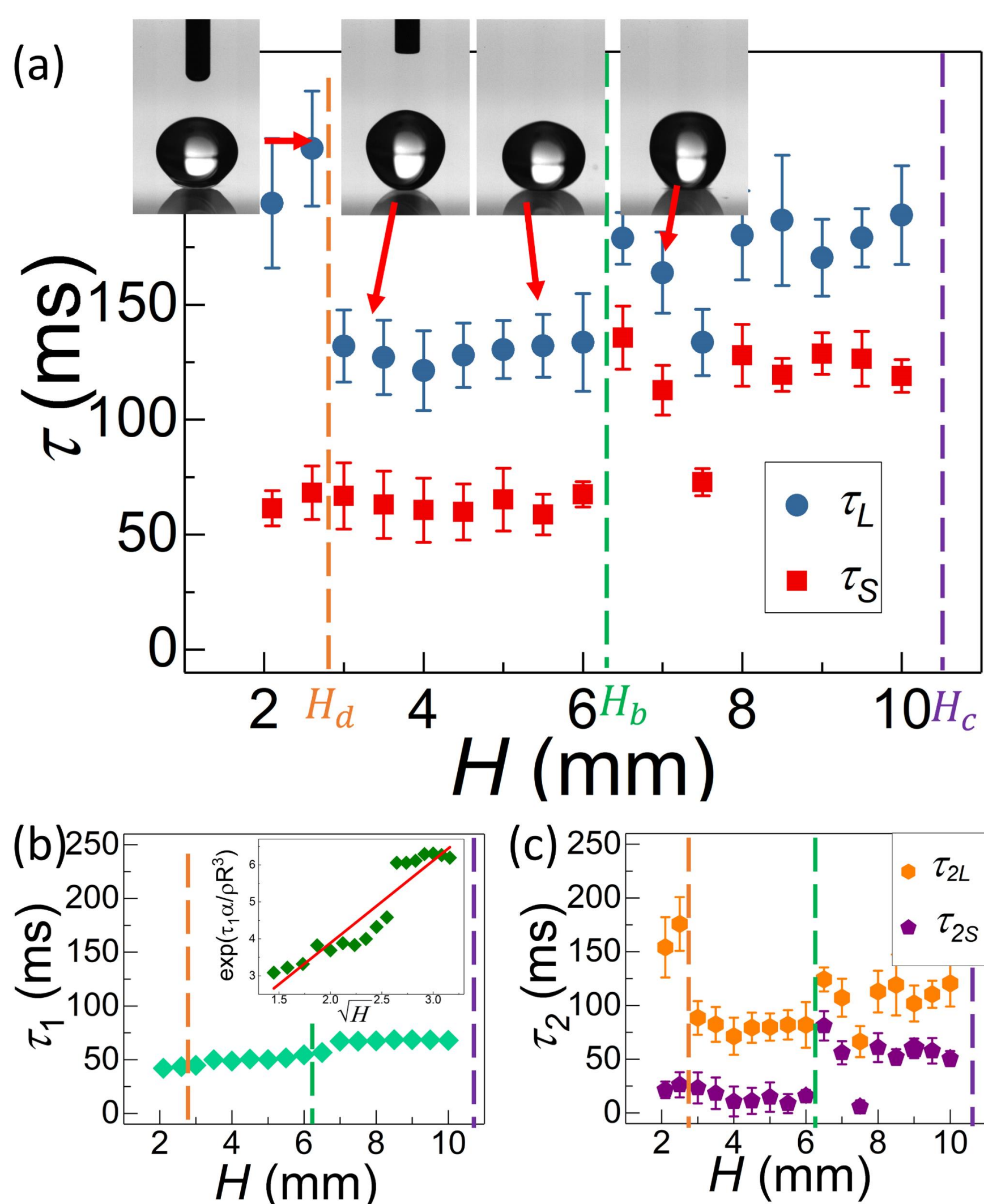


FIG. 2. Residence time τ and its constituents, τ_1 and τ_2 , are plotted respectively in (a, b, c) as a function of height for water droplet of radius $R = 1.79$ mm in air. (a) Snapshots of droplets upon touching the pool indicate that its shape alternates between oblate and prolate with H . (b) The straight line in the inset for $\exp[\tau_1 \alpha / (\rho R^3)]$ vs. \sqrt{H} is the fitting curve with an R-squared value of 0.93. (c) is obtained by subtracting the data in (b) from (a).

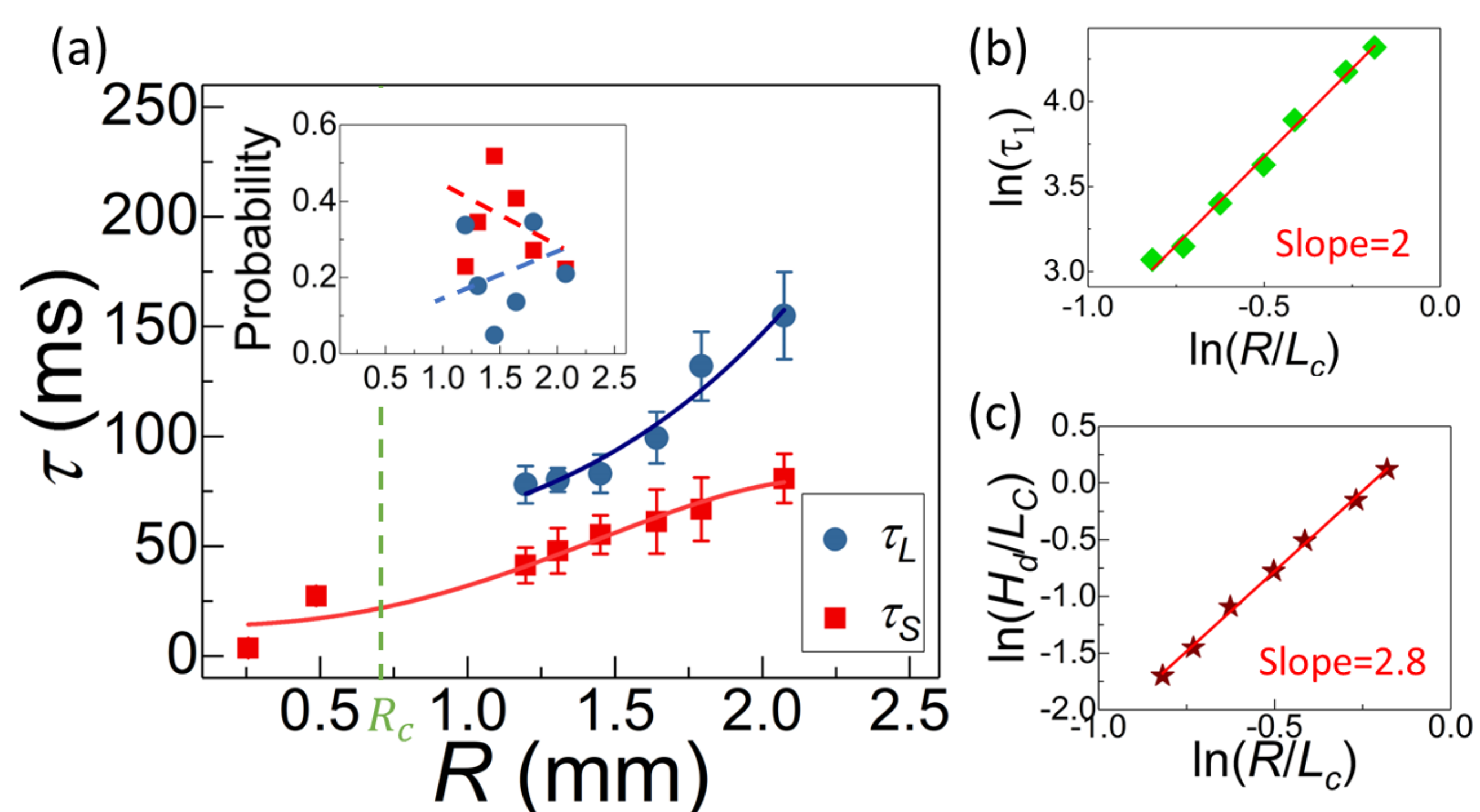


FIG. 3. (a) τ vs. R for $H_d < H < H_b$. Solid lines are fitting curves based on theory. Note that dual τ values only occur when $R \geq R_c$, during which the probability weighting gradually shifts from τ_L to τ_S as $R \rightarrow R_c$ in the inset. (b) τ_1 varies as R^2 for $H_d < H < H_b$. (c) H_d is found to be proportional to $R^{2.8}$, consistent with FIG. 2. Solid lines in (b, c) are linear fitting curves. The capillary length $L_c \equiv \sqrt{\gamma / \rho g}$ is used to render the parameters R and H_d dimensionless.

Reference

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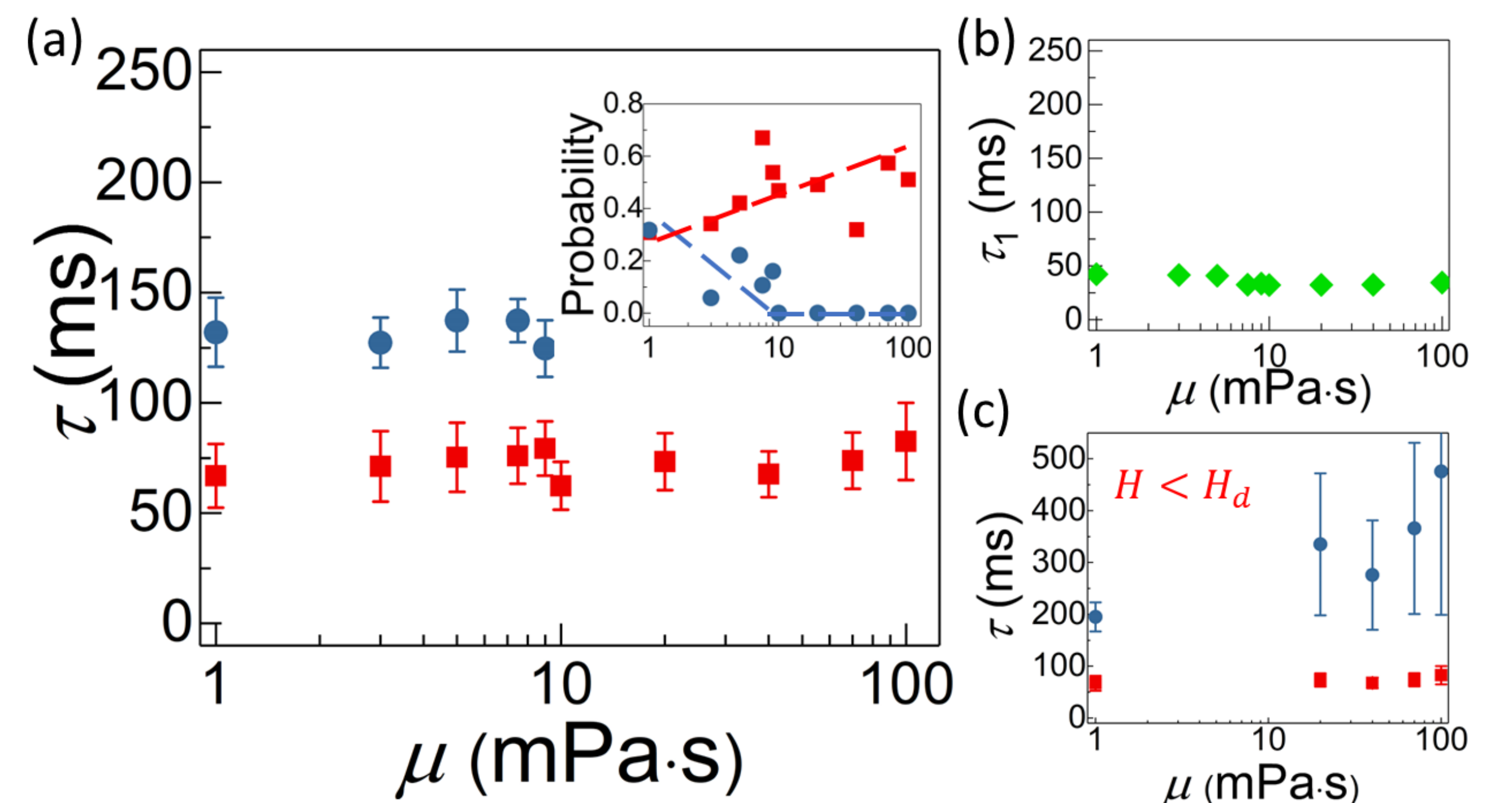


FIG. 4. (a) Residence time τ , roughly independent of viscosity μ for $R=1.79$ mm and $H_d < H=4$ mm $< H_b$, returns to single value when $\mu \geq 10$ mPa.s. The trend of probability shift in the inset indicates that it is τ_L that gets suppressed at large μ . (b) τ_1 decreases as μ increases, as predicted. (c) For $H < H_d$, τ_S remains insensitive to μ as (a) for $R=1.79$ mm, while τ_L increases with μ before vanishing at $\mu=400$ mPa.s, consistent with our expectations.

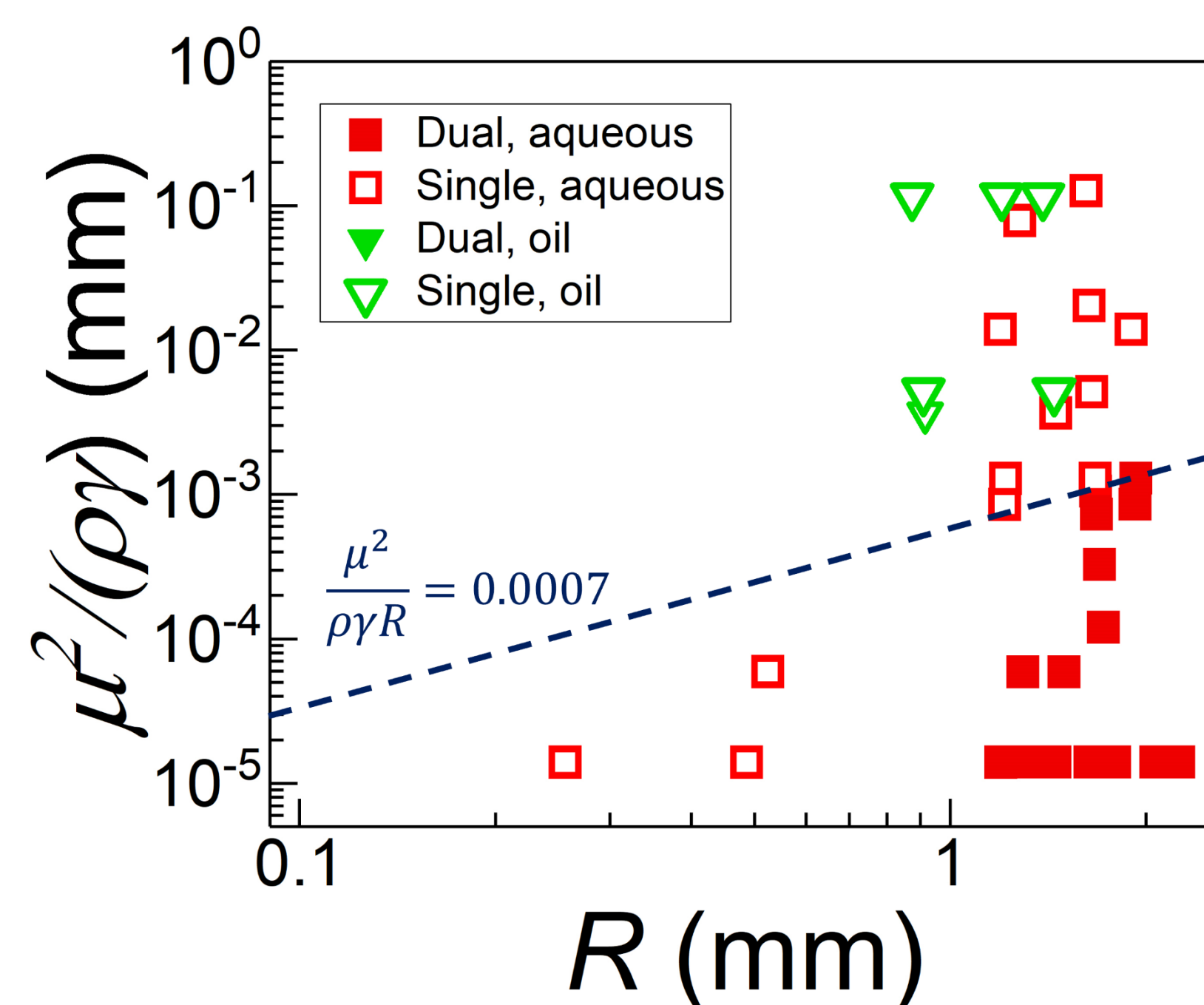


FIG. 5. Data of different liquid mixtures are compiled to show that those exhibiting dual residence time and denoted by solid symbols, such as water, glycerin, ethanol, and silicone oil, tend to fall below the blue dash line, separated from their single-valued counterparts in hollow symbols above. The three small- R points that defy such a rule are created via the coalescence cascade, instead of a syringe like the rest of the samples.

Origin of Dual Residence Time

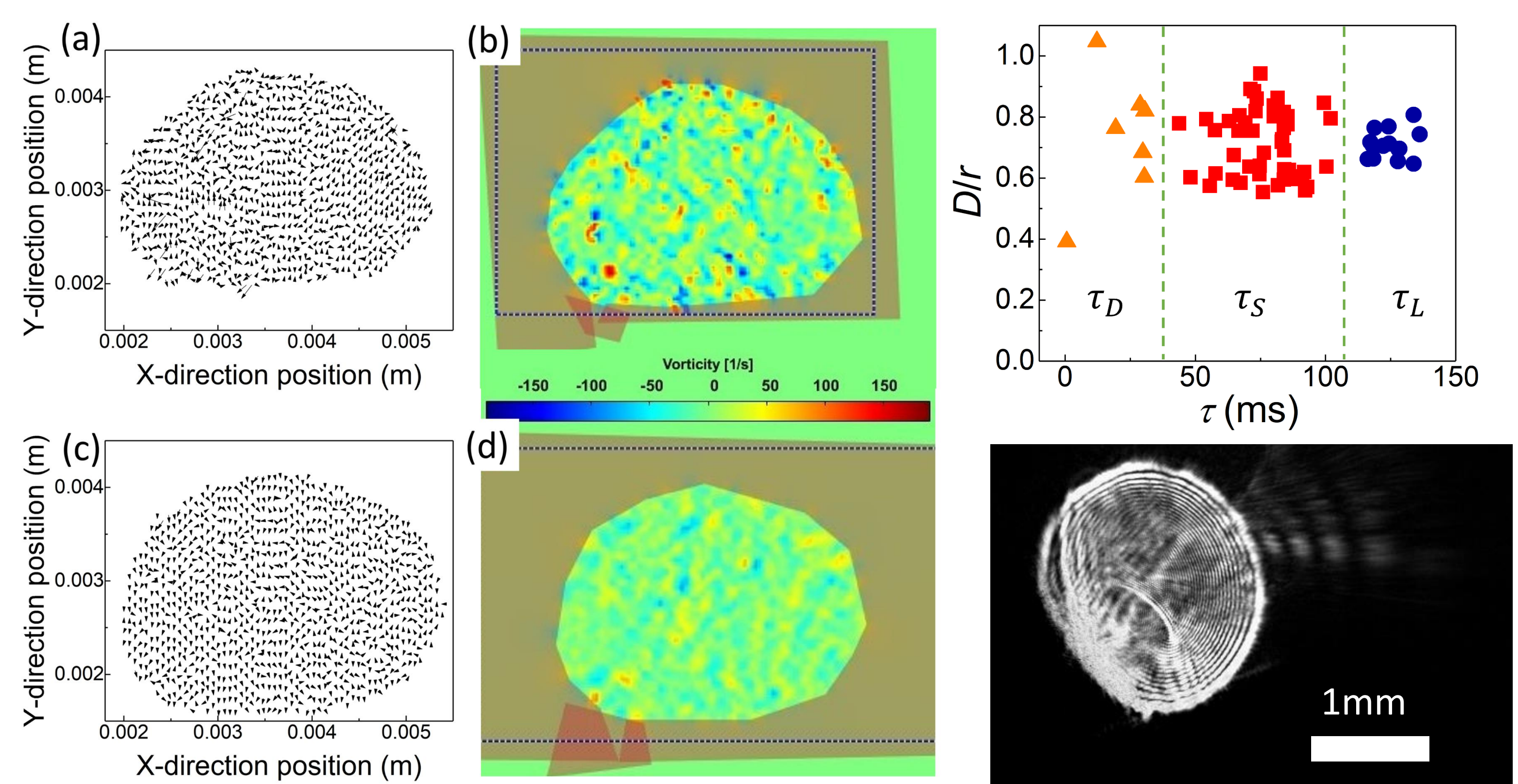


FIG. 6. The averaged flow vectors for the first ten millisecond are determined by PIV for (a) τ_S and (c) τ_L . Both of τ_S and τ_L shows no specific direction of flow. The corresponding vorticity in (b) and (d) rules out the possibility of inward vs. outward internal flow. (e) Distance of coalescence D , normalized by the film radius r , is plotted against the residence time τ for $R=1.79$ mm and $H=4$ mm. Note that droplets always coalesce outside of $r/2$ -range for both τ_S and τ_L . (f) The snapshot of the interference pattern between the droplet and the pool.