Electronic Supplementary Material (ESI) for Soft Matter.

Supplementary Information for

Competing Forces on a Liquid Bridge between Parallel and Orthogonal Dissimilar Fibers

Hossain Aziz and Hooman V. Tafreshi*

Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, Richmond, Virginia 23284-3015

*Corresponding author

Effect of Fiber-Fiber Spacing on Capillary Force

Figure 6 in the paper can be explained using Eq. 8 which indicates that the force acting on a fiber depends on length of the contact line L, immersion angle α, projected wetted area of the fiber A_p, Laplace pressure ΔP, and the volume of the immersed part of the fiber i.e. V_b. It can be seen in Figs. S1a-S1e (in the next page) that L^u, α^u_{avg}, A^u_p, ΔP^u and V^u_b decrease with increasing fiber spacing which results in an increase in F^u (according to Figs. 6a-6b). It was observed that the force F^l acting on the lower fiber also increases with increasing s (see Fig. 6c). F^l is always smaller than F^u, and the difference between them is the weight of the liquid bridge. It is also interesting to note that α changes significantly along the contact line for both the upper and lower fibers (see Fig. S1f).

It can be seen in Figs. 6a and 6b of the paper that F^u just before the start of the dynamic detachment process is same for parallel and orthogonal configurations, although the evolution of F^u with spacing is different for parallel and orthogonal configurations (spontaneous detachment process started at $s \approx 2400\ \mu\text{m}$ for both configurations). The reason behind this was that the values of L^u, α^u, A^u_p, ΔP^u and V^u_b were identical for both configurations at $s \approx 2400\ \mu\text{m}$. This indicates that the shape of the wetted area, contact length, and apparent local contact angle on the upper fiber don't depend on the orientation of the lower fiber.

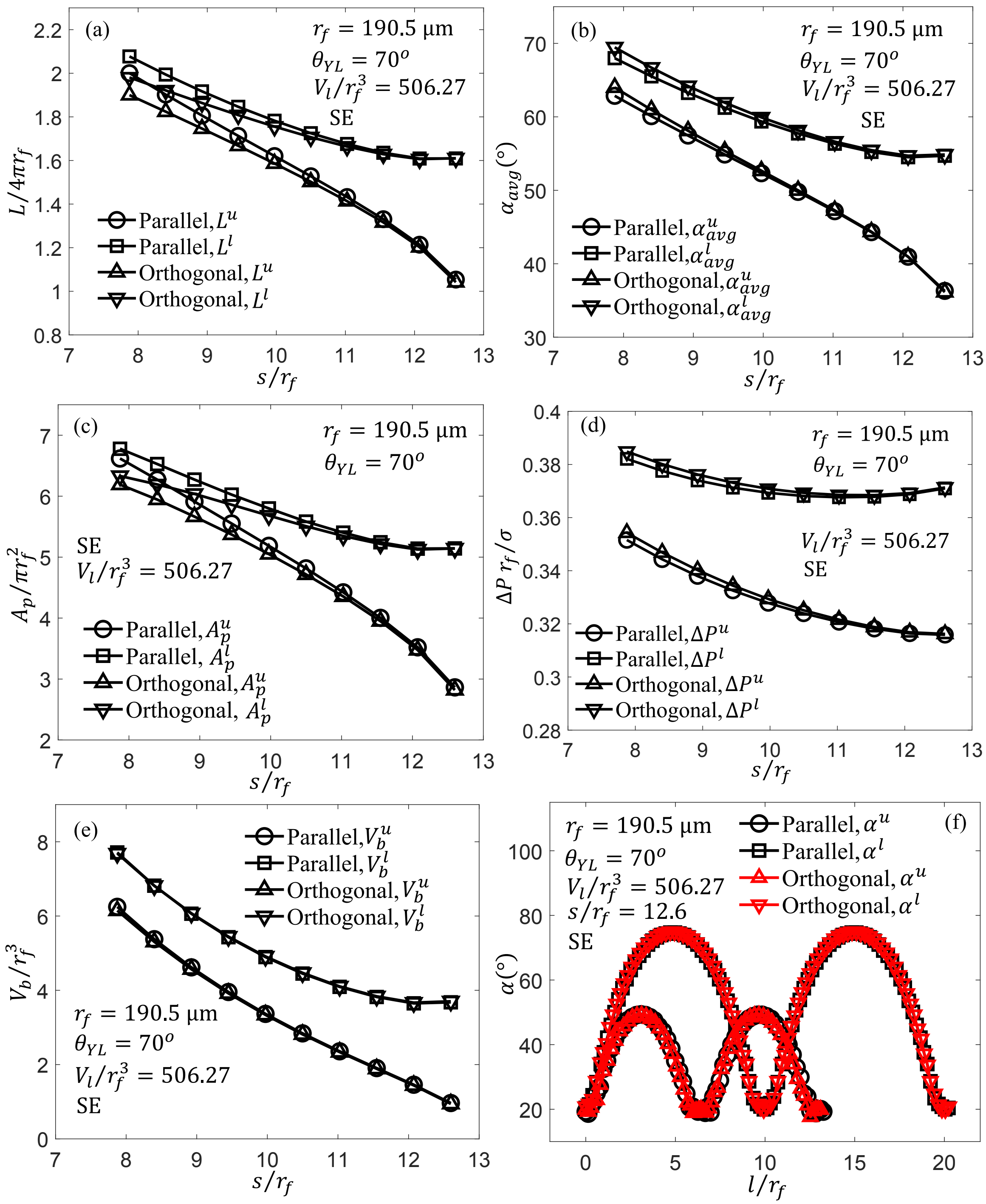

Figure S1: (a) Length of contact line L (non-dimensionalized by $4\pi r_f$) versus fiber spacing for two fibers in parallel and orthogonal configurations. (b) α_{avg} versus fiber spacing. Normalized A_p, normalized ΔP and normalized V_b versus fiber spacing are given in (c), (d), and (e) respectively. (f) α along the contact line for $s/r_f = 12.6$. For all the cases $r_f = 190.5$ μm, $\theta_{YL} = 70^o$, and $V_l/r_f^3 = 506.27$. The liquid used for the experiment was water-glycerol (15% by weight) mixture.

Detachment Force between Two Fibers having same Properties

The values of L_d^u, $\alpha_{avg,d}^u$, ΔP_d^u, $A_{p,d}^u$ and s_d are computed for both the parallel and orthogonal configurations for all the cases shown in Fig 9a in the paper and they are presented in Figs. S2a–S2e here. It can be observed that L_d^u, $\alpha_{avg,d}^u$, ΔP_d^u, $A_{p,d}^u$ and s_d are the same for parallel and orthogonal configurations in all the cases. This again indicates that the detachment force between the liquid bridge and a fiber depends on the shape of the liquid bridge in the vicinity of that fiber (top fiber in the present case) which depends on r_f, θ_{YL} and V_l irrespective of the configuration of the fibers, as long as the fiber is moved slowly (quasi-static process). We also calculated L_d^l, $\alpha_{avg,d}^l$, ΔP_d^l, $A_{p,d}^l$ for the lower fiber for all the cases mentioned above and noted that they did not depend on fiber configuration when the droplet volume and fiber properties were fixed (see Fig. S2). It was also clear that the detachment force increased with decreasing θ_{YL}. The adhesive force between the liquid bridge and the fiber increases with decreasing θ_{YL}.[1] It is therefore expected that the force required to detach the liquid bridge from the upper fiber will increase with decreasing θ_{YL}.

Parameters L_d, $\alpha_{avg,d}$, ΔP_d, $A_{p,d}$ and s_d were also computed for the cases shown in Fig. 9b, but not reported as they were identical for the parallel and orthogonal configurations. Figure 9b also shows that detachment force increases with increasing fiber radius r_f (because L_d^u increases and $\alpha_{avg,d}^u$ decreases with r_f). This is in agreement with the previous work of Farhan and Tafreshi[1] on pendant droplet detachment.

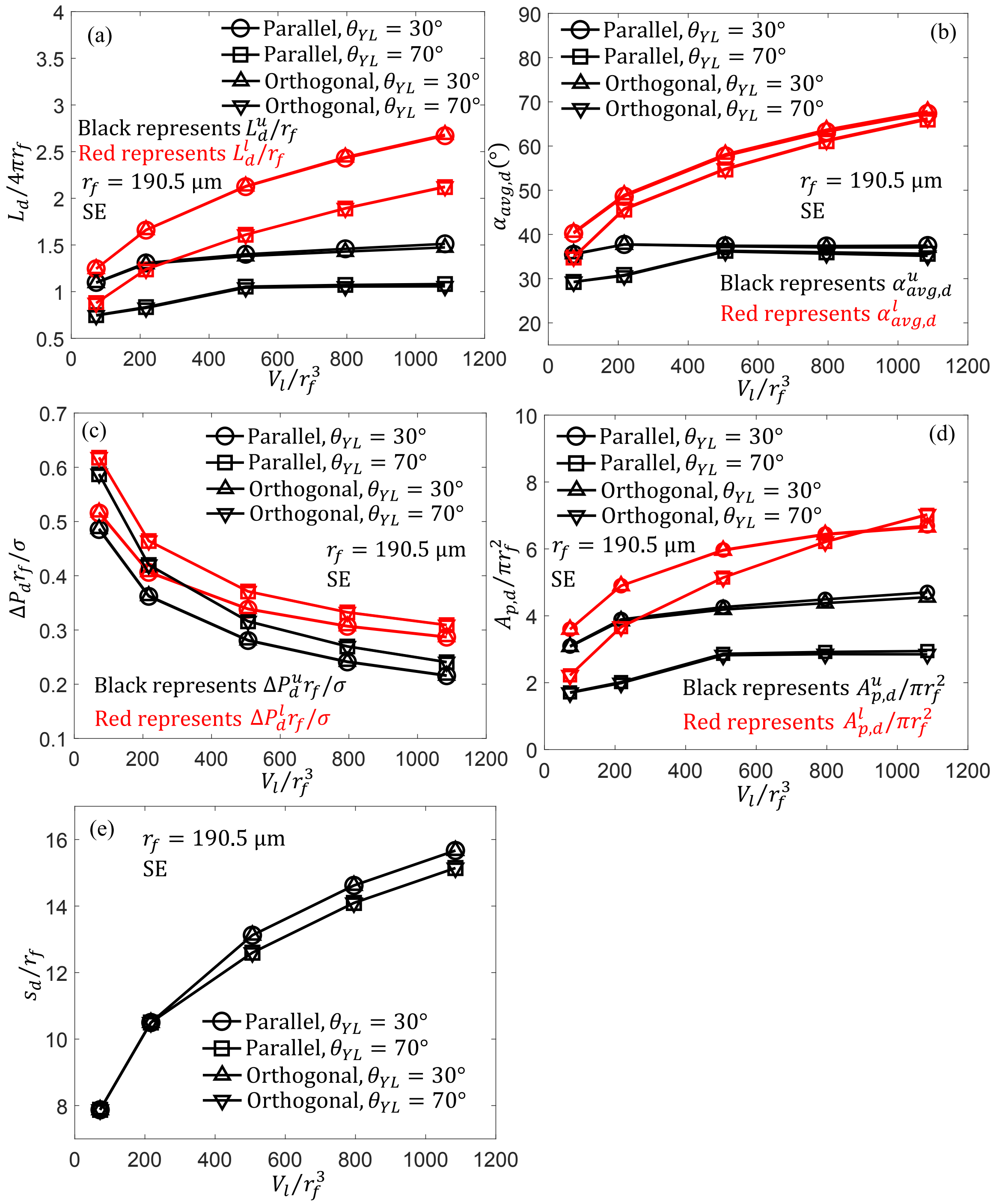

Figure S2: (a) Length of contact line at the onset of detachment L_d (non-dimensionalized by $4\pi r_f$) versus droplet volume. (b) $\alpha_{avg,d}$ versus droplet volume. Normalized ΔP_d , normalized $A_{p,d}$, and normalized s_d versus droplet volume for different θ_{YL} values at $r_f = 190.5$ μm are given (c), (d), and (e) respectively. Here, the subscript *d* indicates the values at the onset of the detachment. The liquid used for the experiment was water-glycerol (15% by weight) mixture.

Detachment Force between Two Fibers having Different Properties

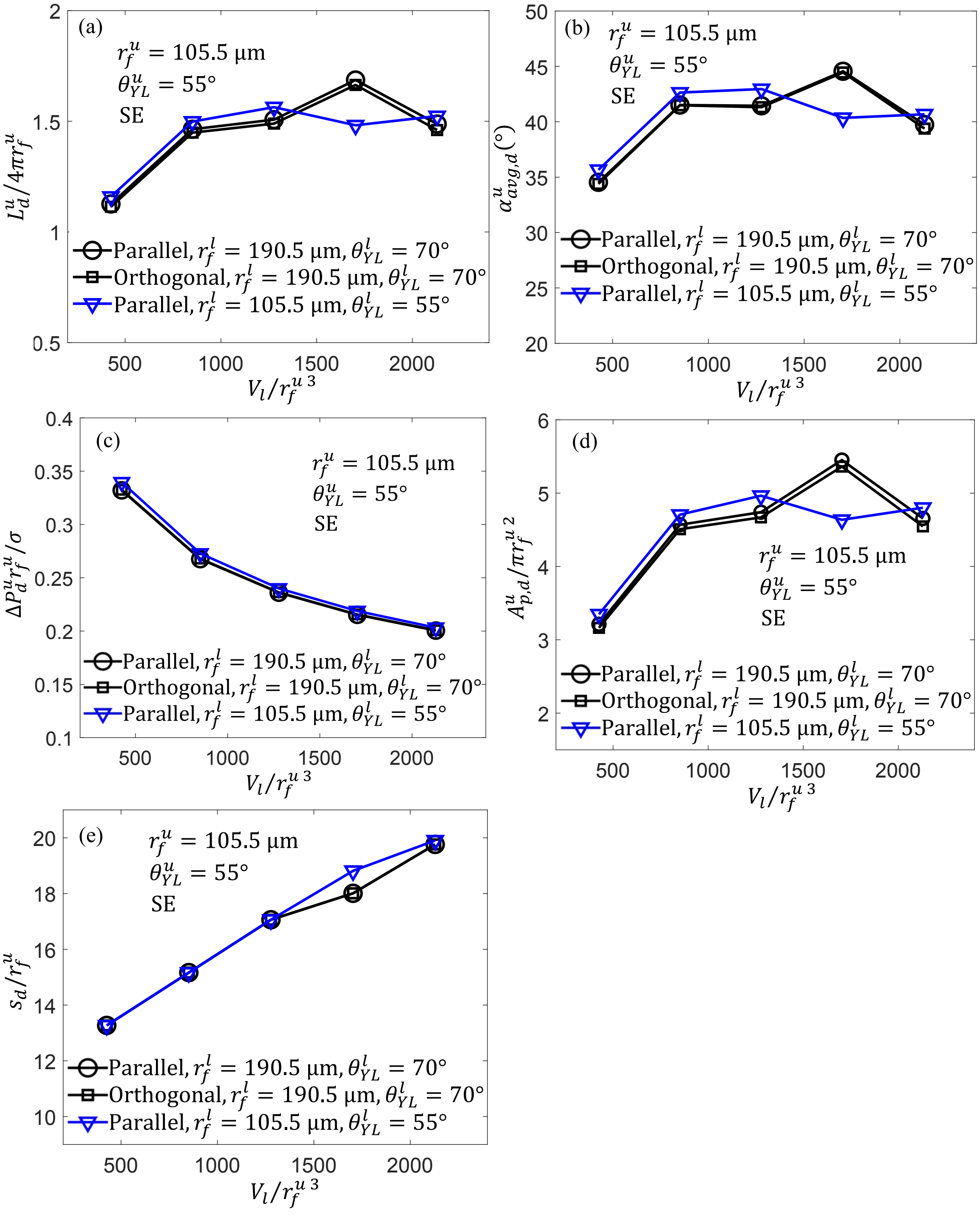

Figure S3: (a) Length of the contact line on upper fiber L_d^u (non-dimensionalized by $4\pi r_f^u$) versus droplet volume. (b) $\alpha^u_{avg,d}$ versus droplet volume. Normalized ΔP_d^u, normalized $A^u_{p,d}$, and normalized s_d versus droplet volume for upper and lower fibers having different properties are given in (c), (d), and (e). For all the cases $r_f^u = 105.5$ μm and $\theta_{YL}^u = 55^o$. The liquid used for the experiment was water-glycerol (15% by weight) mixture.

It can be seen in Fig. 10b in the paper that the detachment force is same for parallel and orthogonal configurations even when the upper and lower fibers have different properties. This can be explained with the help of Figs. S3a-S3e. It can be seen that the parameters L_d^u, $\alpha_{avg,d}^u$, ΔP_d^u, $A_{p,d}^u$ and s_d is same for parallel and orthogonal configurations in all the cases where upper and lower fibers have different properties. Figures S3a-S3e also show that the parameters L_d^u, $\alpha_{avg,d}^u$, ΔP_d^u and $A_{p,d}^u$ do not change significantly with the change in properties of the lower fiber when the properties of the upper fiber is fixed except for $V_l / r_f^{u3} = 1703.23$.

References

1. N.M. Farhan, H.V. Tafreshi, *J. Appl. Phys.*, 2018, **124**, 075301.