Experimental investigation of a quasi-sessile droplet absorption into a capillary

Avick Sinha[1,2], Anastasios Georgoulas[1,2], Matteo Santin[2]
[1]*Advanced Engineering Centre, University of Brighton, Brighton, UK, A.Sinha@brighton.ac.uk*
[1]*Advanced Engineering Centre, University of Brighton, Brighton, UK, A.Georgoulas@brighton.ac.uk*
[2]*CRMD, University of Brighton, Brighton, UK, M.Santin@brighton.ac.uk*

Abstract:

The primary goal of a wound dressing design and development is to accelerate the healing process, making the selection of an appropriate dressing type crucial. The complex topology of wound dressings presents challenges in visualizing the flow within their porous structure. However, the absorption of wound exudate by dressings can be investigated through high-resolution laboratory experiments. As a first step, an experimental study examined how exudate is absorbed into a single capillary tube from a quasi-sessile droplet. The findings showed that higher exudate viscosity leads to slower absorption and alters its behaviour inside the capillary tube.

Keywords: Droplet, Capillary, Exudate, Porous media

Introduction:

Wound exudate, the fluid that oozes from a wound, plays a critical role in the wound healing process [1]. Therefore, selecting an appropriate wound dressing based on the exudate's viscosity is essential to accelerating healing while maintaining a moist environment for tissue repair. White and Cutting [2] emphasise that effective clinical management of exuding wounds depends on an accurate assessment of the exudate's volume and viscosity. However, investigating exudate absorption within wound dressings is challenging due to the complex and heterogeneous structure of the porous material, which complicates the visualisation and tracking of fluid flow. Most previous studies have focused on single pores to analyse and quantify underlying mechanisms, typically using impacting droplets [3]. While Andreadki et al. [4] conducted a numerical study on the absorption of quasi-sessile droplets into wound dressing capillaries, observing that both liquid viscosity and pore diameter are key factors influencing absorption regimes and rates, no experimental work using actual exudate properties on single capillary tubes has been reported. In this study, a preliminary experimental investigation was performed to examine the absorption of a quasi-sessile droplet into a single pore, aiming to uncover the fundamental physics of exudate absorption in wound dressings.

Experimental Material and Method:

The experimental setup consists of a capillary tube with an inner diameter of 1.6 mm and an outer diameter of 2.6 mm. Simulated Body Fluid (SBF) was used as a biologically safe surrogate for wound exudate to study absorption characteristics within a porous medium. SBF closely mimics the ionic composition of human plasma, making it a suitable substitute for in-vivo conditions [5]. To investigate the effect of increased exudate viscosity, Dextran Blue (DB) was added to the SBF at a concentration of 2 mg/mL, raising the dynamic viscosity by approximately 1.26 times that of pure SBF (the other fluid properties remain relatively same). The optical setup included an LED light source for continuous illumination, paired with a high-speed camera and long-distance microscopic lens. Images were captured with high temporal resolution (20 kHz) and a spatial resolution of 1024 $\times$ 1024 pixels to observe the microsecond-scale dynamics of drop absorption. After calibration, the spatial sensitivity of the microscope was determined to be 10 μm/pixel. Droplets were formed by pushing air through a small syringe connected to a larger syringe via a pneumatic tube. This process generated a droplet at the tip of a hypodermic needle, which was then quasi-statically detached onto the capilary tube inlet section. Using a 27G needle, the average droplet diameter (D_D) across all trials was 2.13 mm, with a variation of ± 0.07 mm at a 95% confidence interval. To minimize the droplet's kinetic energy, leading to a quasi-static deposition, the release height was kept as low as possible.

Results and discusison:

Figure 1a shows the time evolution of droplet absorption in the capillary for two different fluids. The capillary tube used is hydrophilic. It was observed that the SBF droplet was fully absorbed, consistent with Delbos et al.'s findings, where slow-moving droplets or thin tubes led to complete absorption, a phenomenon they termed "total impregnation". The addition of Dextran Blue (DB), which increases the fluid's viscosity, slowed down the droplet's penetration. This is due to the higher internal friction in the fluid, which resists rapid deformation and spreading. This observation can also be substantiated from Fig. 1b. Figure 1b shows the normalized droplet area against time. The area of the droplet is normalized using the droplet area at the point of impact on the capillary. It can be observed from Fig. 1b that after landing on the capillary tube, its area remains relatively unchanged initially because the capillary forces and surface tension stabilise the droplet's shape. During this time, the absorption rate is slow, as the liquid needs to overcome internal friction and begin penetrating the pore. After this initial period, a rapid decrease in droplet area occurs due to the onset of capillary-driven flow. Once the liquid begins to be absorbed into the capillary tube, the process accelerates as the surface tension pulls the fluid into the pore. This creates a faster uptake of the droplet, causing its area to shrink quickly. The transition from a slow to rapid absorption phase is driven by the balance of capillary forces, fluid viscosity, and surface tension acting on the droplet.

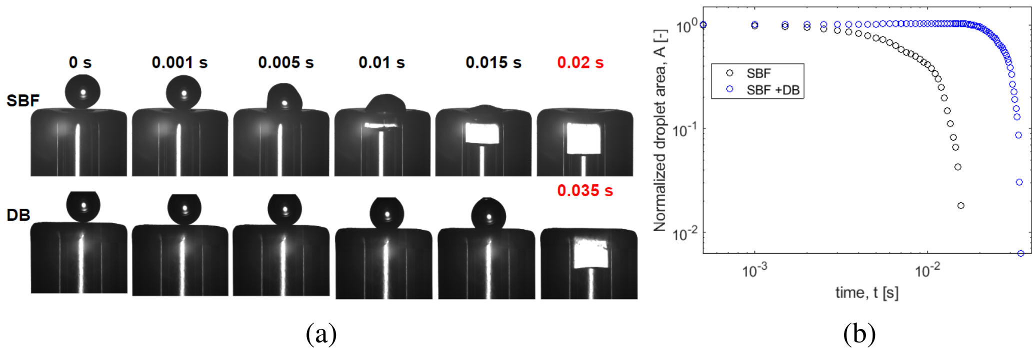

Figure 1: (a) Time-sequence of droplet penentration (b) Normalized area of the droplet againt for two different working fluids- SBF and SBF + DB

Conclusion:

The forced impregnation of a quasi-sessile droplet into a single cylindrical pore, using two fluids of different viscosities, is investigated. In all cases, complete droplet absorption is observed within the hydrophilic capillary, with increased viscosity resulting in longer absorption times. Clinically, selecting the appropriate wound dressing is critical when managing exudates with higher viscosities. A parallel in-house study, conducted as part of the same research project, revealed that exudates exhibit shear-thinning properties. Future research will therefore focus on incorporating shear-thinning fluids and conducting experiments involving simultaneous droplet impacts on a single pore.

Acknowledgments:

This work is supported by the UKRI Engineering and Physical Science Research Council, grant number EP/W023164/1

References

[1] Forss, J. R. *Does exudate viscosity affect its rate of absorption into wound dressings?*, Journal of Wound Care. **31(3)**, 236–242 (2022).

[2] White, R., & Cutting, K. F. *Modern exudate management: a review of wound treatments.*, World Wide Wounds. **1**, (2006).

[3] Delbos, A., Lorenceau, E., & Pitois, O. *Forced impregnation of a capillary tube with drop impact.*, Journal of colloid and interface science. **341(1)**, 171–177 (2010). World Wide Wounds. **1**, (2006).

[4] Andredaki, M., Georgoulas, A., & Marengo, M. *Numerical investigation of quasi-sessile droplet absorption into wound dressing capillaries.*, Physics of Fluids. **32(9)**, (2020).

[5] Baino, F., & Yamaguchi, S. *The use of simulated body fluid (SBF) for assessing materials bioactivity in the context of tissue engineering: review and challenges.*, Biomimetics. **5(4)**, 57 (2020).