Blood viscosity estimation in a capillary microchannel

D. Pasias and E. Kaliviotis
Dept. of Mechanical Engineering and Material Science and Engineering,
Cyprus University of Technology,
Cyprus

10th International Congress on Rheology, Athens, Greece, July 29 - August 4, 2023

Abstract. Capillary viscometry can be a practical technique to provide viscosity estimates for small volumes of fluids. The viscosity can be estimated if the pressure drop, the flow rate and the length of the capillary are known. Non-Newtonian models can be incorporated. By considering the propagation of the flow in the capillary and accepting a power-law approximation for blood viscosity, the consistency index and exponent can by estimated. The aim of this work, was to estimate the viscosity of various blood samples, for flows in a converging, rectangular microfluidic channel. The calculated viscosity was compared with the viscosity measurements produced using a commercial instrument.

Methodology.

Capillary microchannel:

- Convergent geometry.
- Channel width: entrance 5mm, exit 1mm. Depth: ~100 μm, length: 20mm.
- Meniscus velocity: Tracking velocimetry. Local velocity field: μPIV techniques.

Meniscus velocity vs flow length:

- Power-law viscosity model, and Young-Laplace pressure drop[1,2].

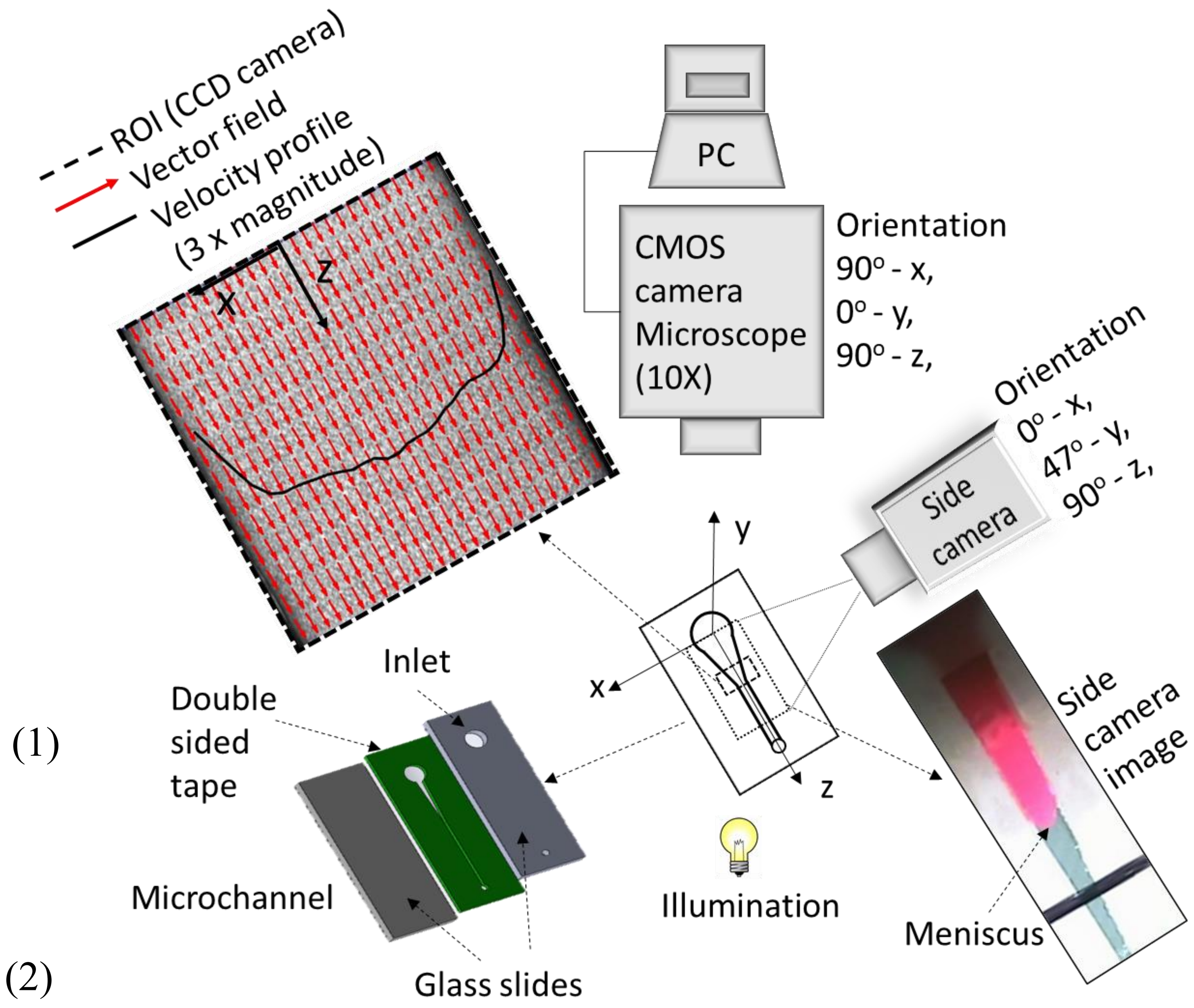
$$V(t)^n = \left(\frac{n}{n+1}\right)^n \left[\frac{\sigma\cos(\theta_C)}{hkL(t)}\right] \left[h^{\frac{n+1}{n}}\left(1-\frac{n}{2n+1}\right)\right]^n \quad (1)$$

Rearranging (1):

$$\frac{1}{L(t)} = \left(\frac{2n+1}{n}\right)^n \left[\frac{hk}{\sigma\cos\theta}\frac{1}{h^{n+1}}\right] V(t)^n = CV(t)^n \quad (2)$$

$$\log\left(\frac{1}{L(t)}\right) = \log C + n\log V(t) \quad (3)$$

n and k: power law indices,
σ and θ_c : surface tension and contact angle,
h and L: gap and flow length.



Setup[3,4]:

- CMOS camera: IDT X3, 2000 images, 1250 fps.
- Side camera: JVC TK-C1380 color, 60mm Panasonic lens.
- Microscope: BX51 OLYMPUS, 10X-objective, NA=0.25.
- Image spatial resolution: 1.65 μm/pixel, μPIV analysis: Matlab.

Viscosity measurements:

- Cone-plate, Brookfield LVDT II instrument.
- Viscosity derived at shear rates between 251.2 (starting) and 1.4 s-1 (final).
- Rate sweep mode: 30 seconds measurement time, per shear rate point (17 points).

Blood samples:

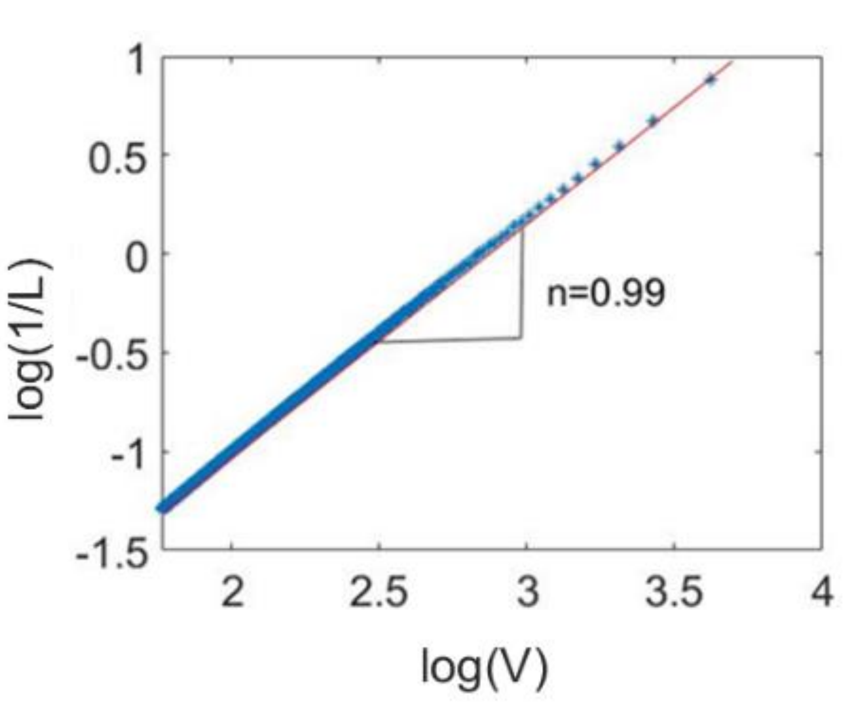
- 30ml (EDTA anticoagulated) from normal, healthy participants (n=9).
- Whole blood (WB).
- RBC suspensions in phosphate buffer saline (PBS).

(Bioethics ref.: ΕΕΒΚ/ΕΠ/2016/18)

Results

Velocity vs flow length.

- Non-aggregative blood suspension.
- RBC aggregation and shear thinning behavior suppressed.
- n~1, Newtonian behaviour.



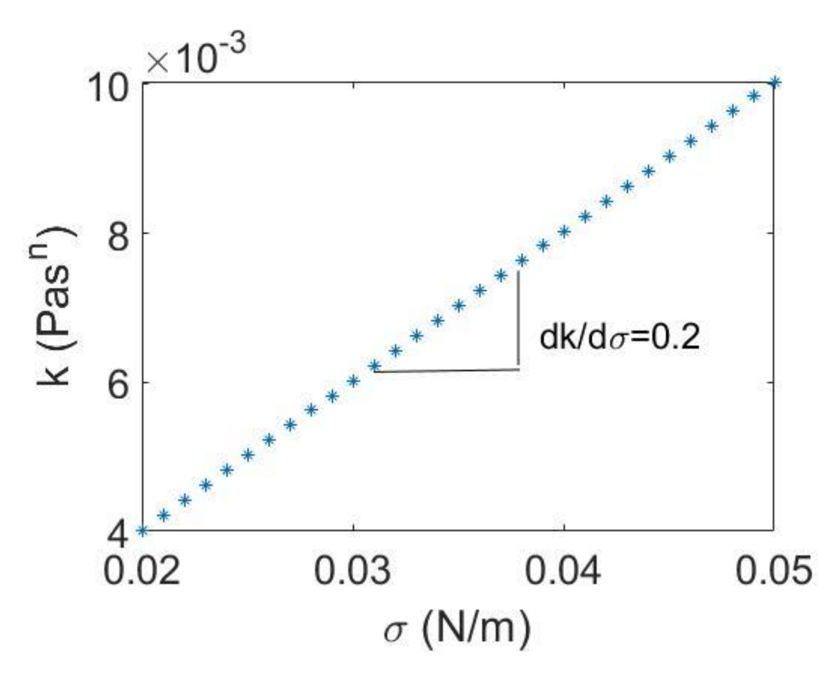
Predicted vs measured viscosity.

- Percent viscosity differences: capillary derivation vs viscometer.
- Aggregative whole blood: strong disaggregation conditions in the flow.
- Shear thinning behavior suppressed.

	Sample viscosity difference μ_d (%)	
Shear rate (s^{-1})	Whole Blood	Blood suspension
251.2	-8.94	3.5
125.9	-19.97	-11.33
31.58	-46.75	-39.91
7.875	-67.43	-60.44
3.975	-77.6	-74.99

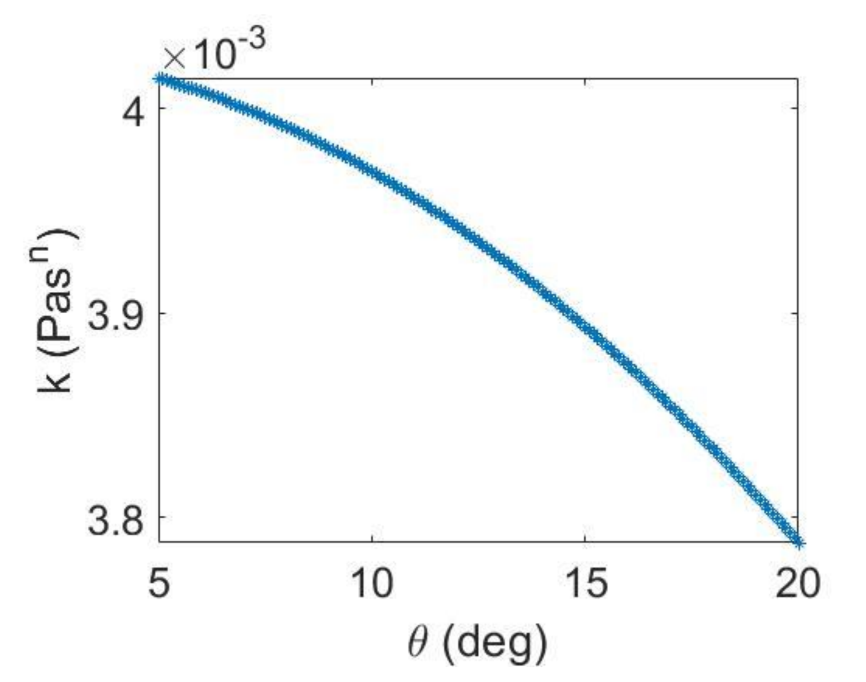
Dependency of k on surface tension.

- k increases 2.5 times for the range of σ: 0.02N/m < σ < 0.05N/m.
- Surface tension affects k.



Dependency of k on contact angle

- k decreased ~ 5%, from θ = 5° to θ = 20°.
- θ does not significantly affect k.



Remarks

- Strong shearing conditions in the flow, and small channel length and duration, suppresses RBC aggregation and shear thinning.
- Calculated viscosity values closer to the high-shear measured viscosity.
- Fluids follow a Newtonian behavior due to reduced RBC aggregation under the specific shearing conditions.
- High shear viscosity of blood can provide information about the general viscous status of the fluid.

Acknowledgments
The study has been supported by funding from the internal Start-Up Grants of the Cyprus University of Technology, by a grant from the Cyprus Research and Innovation Foundation (ref.: EXCELLENCE /0918/0215), and by funding from the Youth Board of Cyprus (Dimitris Pasias scholarship).

References:
[1] Srivastava N and Burns MA. Anal Chem. 2006;78(5):1690–6. 10.1021/ac0518046
[2] Dongyang K, etal. In: 2015 IEEE, NEMS 2015. p. 1–4. 10.1109/NEMS.2015.7147343.
[3] Pasias D., Passos A., Constantinides G., Balabani S., Kaliviotis E. Surface tension driven flow of blood in a rectangular microfluidic channel: Effect of erythrocyte aggregation. Phys Fluids. 2020;32(7). 10.1063/5.0008939.
[4] Pasias D., Koutsokeras L., Passos A., Constantinides G., Balabani S. and Kaliviotis E. Effects of biomechanical properties of blood on surface tension driven flows in superhydrophilic channels. Physics of Fluids. 2022;34. 10.1063/5.0088643.

Republic of Cyprus
European Union
European Regional Development Fund
Structural Funds of the European Union in Cyprus
The Framework Programme RESTART 2016-2020 for Research, Technological Development and Innovation is co-funded by the Republic of Cyprus and the European Regional Development Fund.