

Proving it Works: Fluid Viscosity Verification in a Diamond Anvil Cell



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Introduction and Purpose

The rate and volume of transport of crustal fluid is dependent on the fluid viscosity. Measurements of geophysically relevant fluid viscosities are sparse at the high pressure and temperature conditions of the deep crust. Determination of these rates facilitates better understanding of the time requirements for many geologic processes, specifically the complex movements and changes of crust involved in subduction zones.

The Diamond Anvil Cell (DAC) has been used for over half a century to simulate deep earth pressures. Recent experiments to measure viscosity in the DAC using Brownian motion of suspended particles in water have established the feasibility of using the DAC as a viscometer. However, this method must be verified over a large range of fluid viscosities. Studying fluids with viscosities ranging between 0.4 mPa·s and 2 mPa·s at STP can verify the success of DAC-based viscosity measurements at high pressure and temperatures.

Figure 1

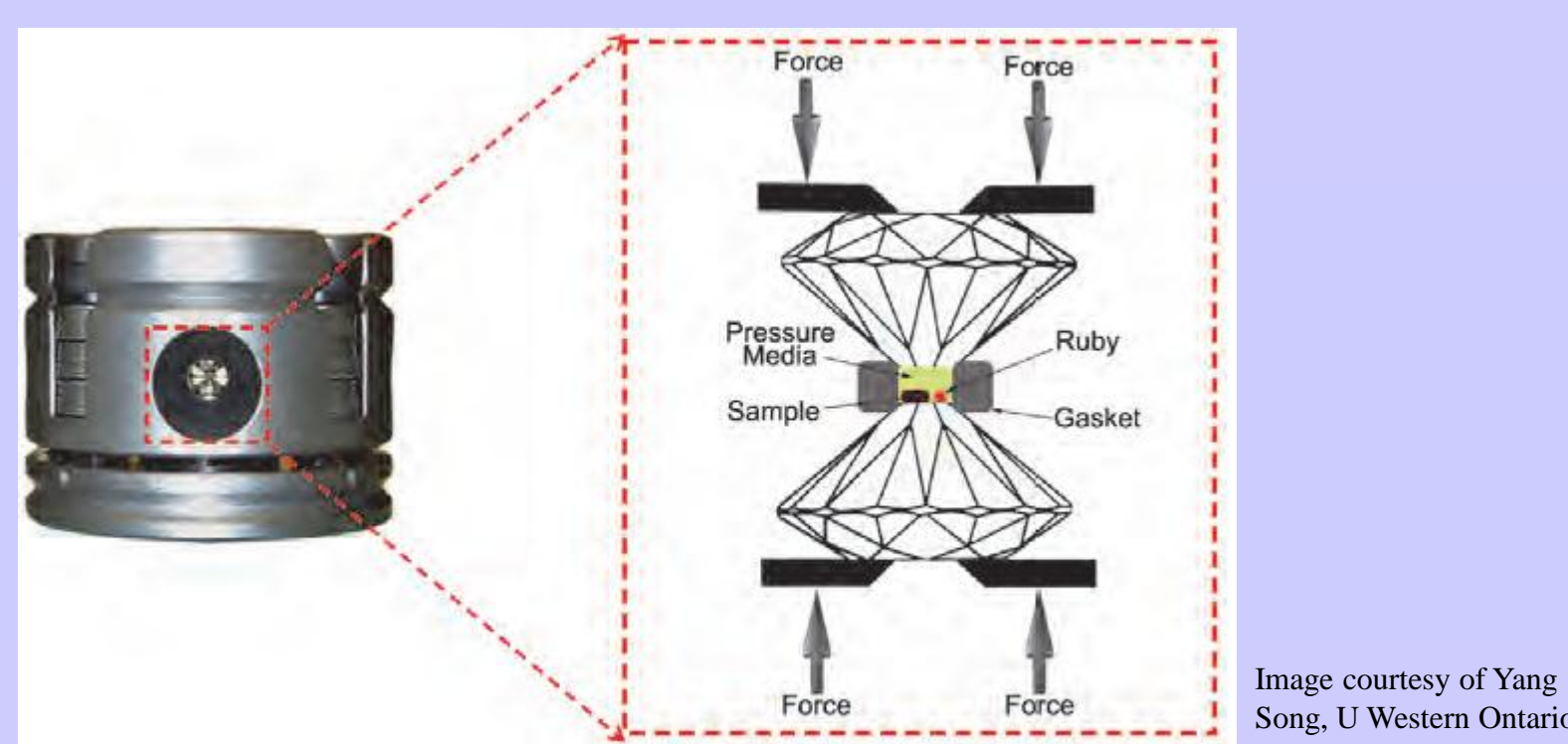


Image courtesy of Yang Song, U Western Ontario

Materials and Methods

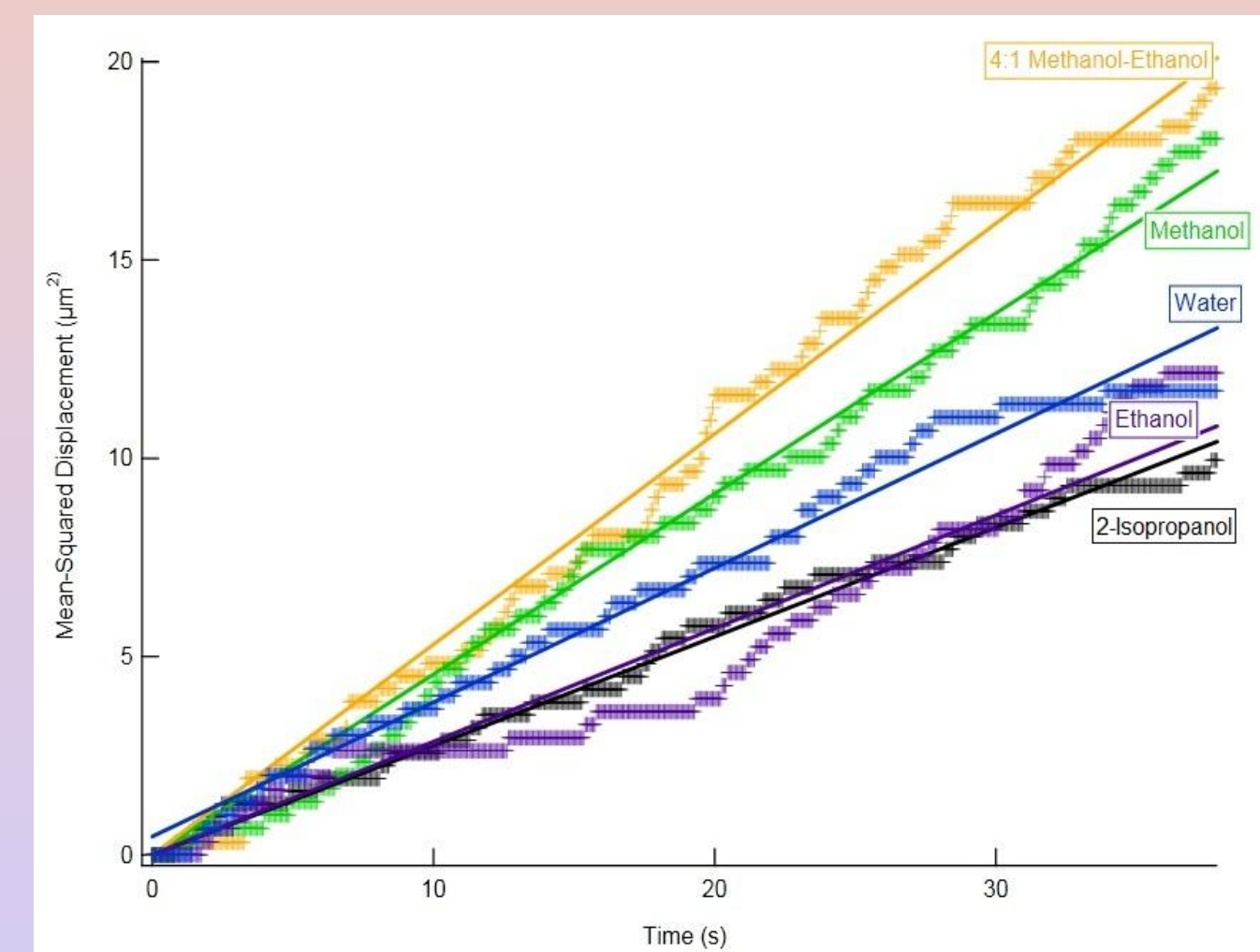
- 1.4 μm polystyrene particles immersed in water were dried out and scraped into a vial of ethanol, 2-isopropanol, methanol, water, or a 4:1 mixture of methanol to ethanol
- A drop of this solution containing the particles suspended in the fluid was placed on a gasket hole of 188 μm and enclosed in a DAC (Figure 1)
- Brownian motion of these particles was observed and recorded on video for 40 seconds
- The videos were analyzed using a particle tracker on Matlab to determine the mean-squared displacement of each particle over the 40 second movie
- The best-fit line of this displacement was obtained using Igor Pro and to determine the viscosity of the containing fluid, the slope was inserted into the Stokes equation
- The average viscosity of all particles in each video was used as the measured viscosity for the trial and then corrected for gasket thickness
- These measured viscosities were finally plotted against the actual viscosities listed in the CRC for fluids at 25°C along with a 1:1 line for comparison

Brownian Motion

Brownian motion is the apparent random movement of particles suspended in a fluid. The motion is the result of molecular movements of the fluid and the mean-squared displacement of a particle as a function of time is $\langle [r(t)]^2 \rangle = \frac{4 * k_b * T}{6 * \pi * \eta * \alpha}$, where k_b is Boltzmann's constant, T is temperature in Kelvin, α is the radius of the particle, η is viscosity of the fluid, and t is time. These movements can be observed through a DAC and recorded on video.

Results

Figure 2



In Figure 2, the mean-squared displacement for a particle suspended in each liquid is shown. The 4:1 Methanol-Ethanol solution was the least viscous of the five, allowing for the greatest displacement to take place. Conversely, the 2-isopropanol had the greatest viscosity and allowed for the smallest displacement. The other three fluids had intermediate viscosities.

Figure 3

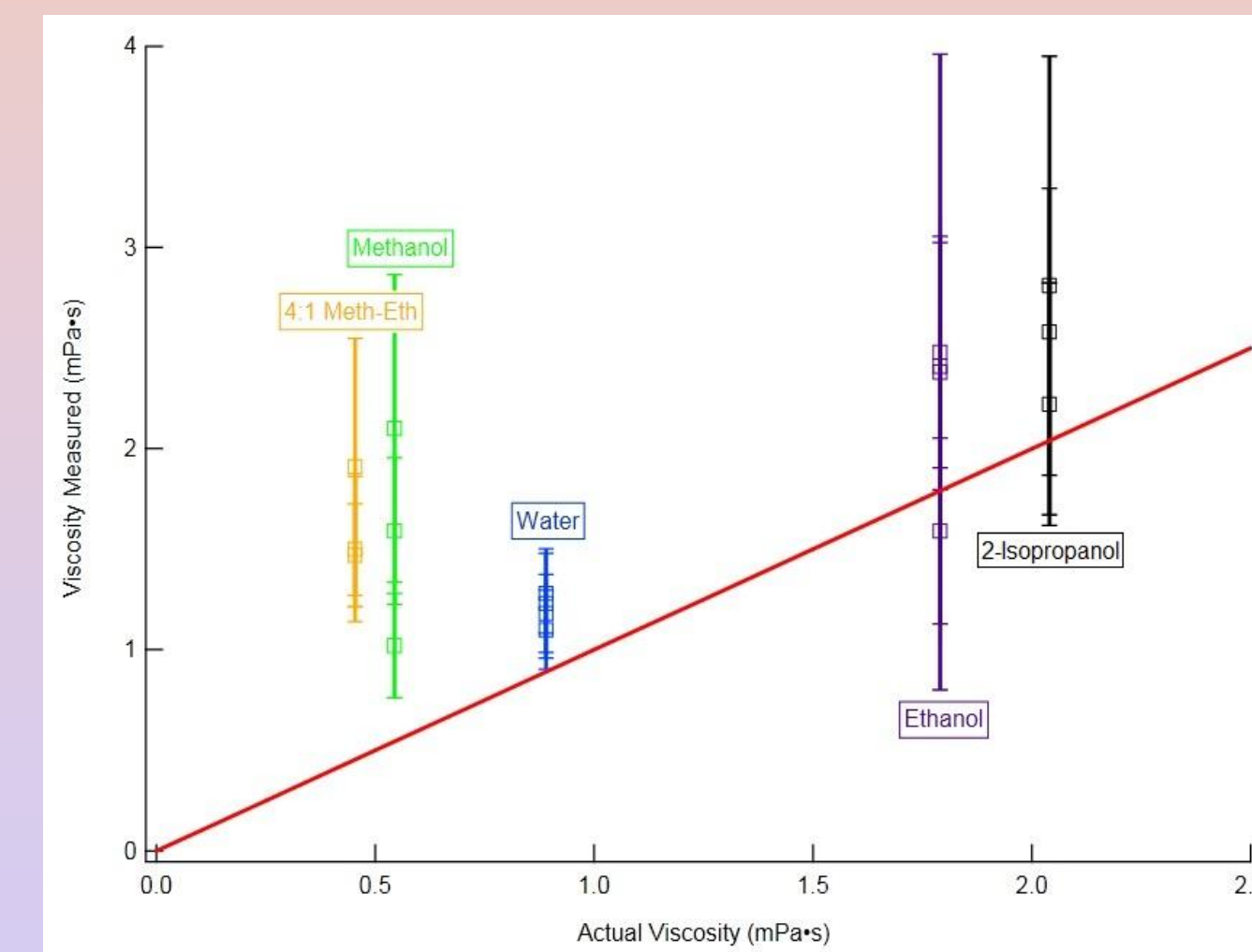


Figure 3 shows the measured viscosity of each fluid is plotted against the actual values for 25°C from the CRC. A 1:1 line is also plotted to show ideal results. The 4:1 solution viscosity was taken from Grocholski et al. (2005) rather than the CRC. All measured viscosities were between 1.15 mPa·s and 2.85 mPa·s. These values were between 2-5 times greater than the expected values.

Figure 4

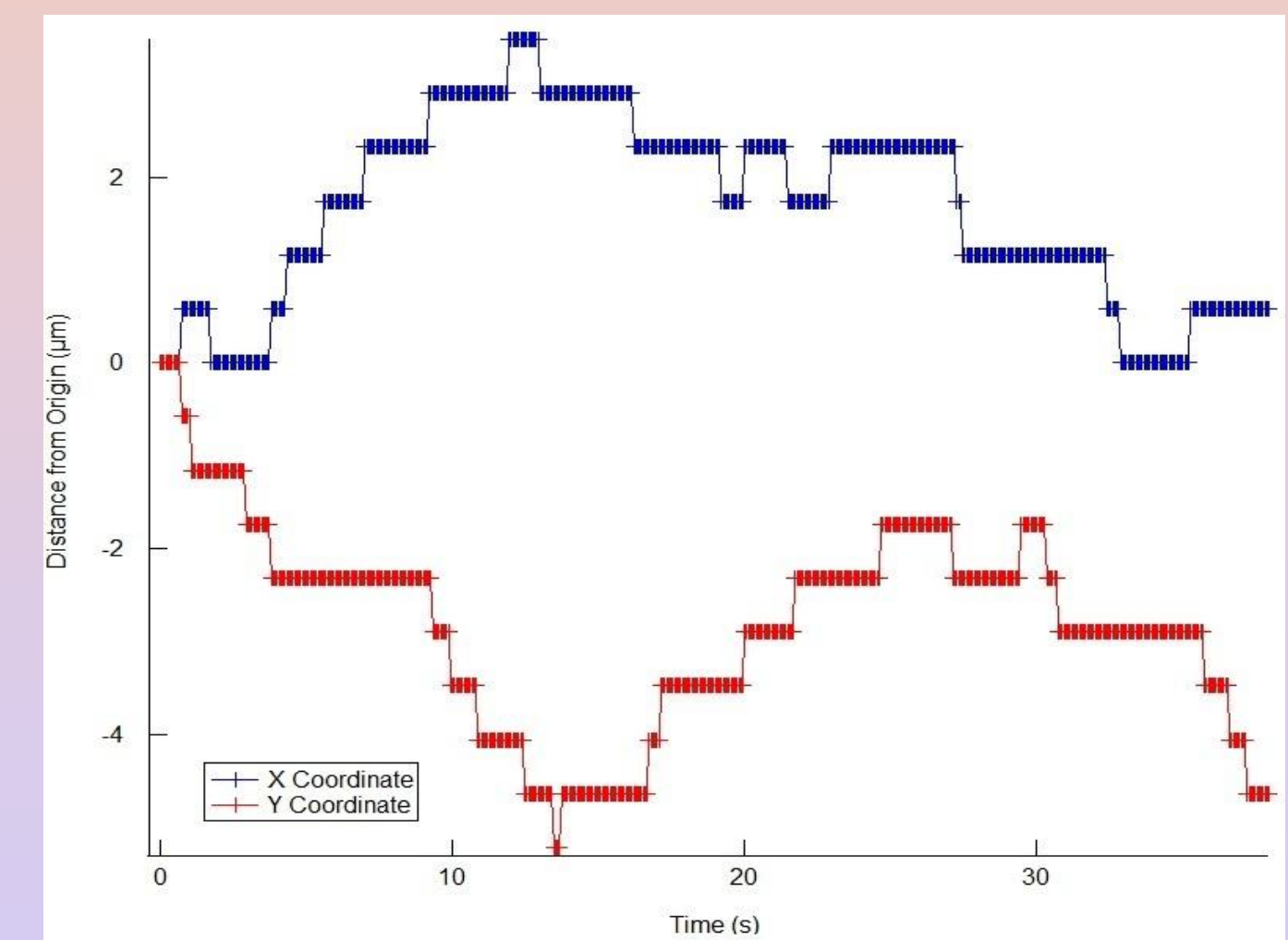


Figure 4 shows the position of a particle over the 40 seconds along the x and y axes. The x position is shown in blue while the y position is shown in red. The particle appears to jump up and down or left and right at random, with no real linear directionality to its path

Discussion

The viscosities measured generally showed to have higher values than those listed in the CRC. Viscosity is highly sensitive to temperature and one source of discrepancy results due to the difference in CRC temperature (25°C) and that in the lab (20.6°C). The results of the trials did show consistency amongst themselves, suggesting the need for a calibration technique to lower the found viscosities to actual. Water, ethanol, and 2-isopropanol had closer results to the actual values than the 4:1 solution and methanol which suggests that the technique has greater accuracy with higher viscosity fluids.

Conclusion

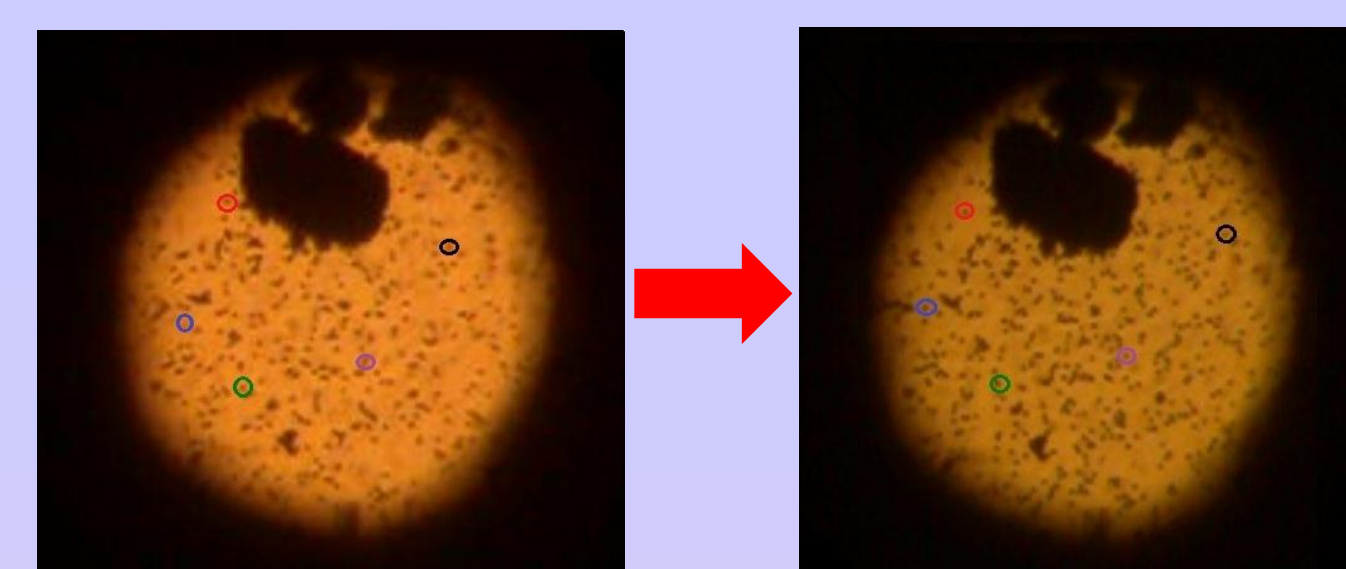
The results found were all on the same order of magnitude as the actual viscosities of the 4:1 methanol-ethanol solution, ethanol, 2-isopropanol, methanol, and water. With the development of proper calibration techniques, accurate viscosity values can be determined using the Diamond Anvil Cell as a viscometer. Future research will examine the effects of high pressure conditions on the viscosities of these fluids.

Acknowledgements and References

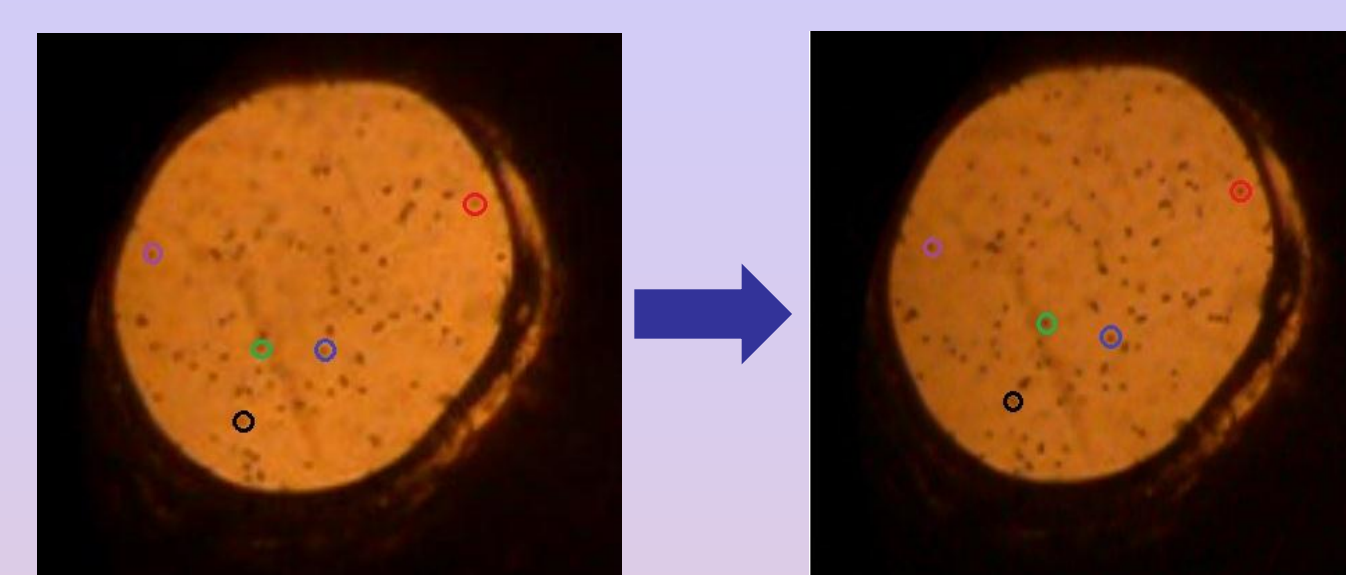
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Works Cited
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Grocholski, B. and Jeanloz, R. (2005). High-pressure and -temperature viscosity measurements of methanol and 4:1 methanol:ethanol solution. *Journal of Chemical Physics*, 123, 204503. doi: 10.1063/1.2110068
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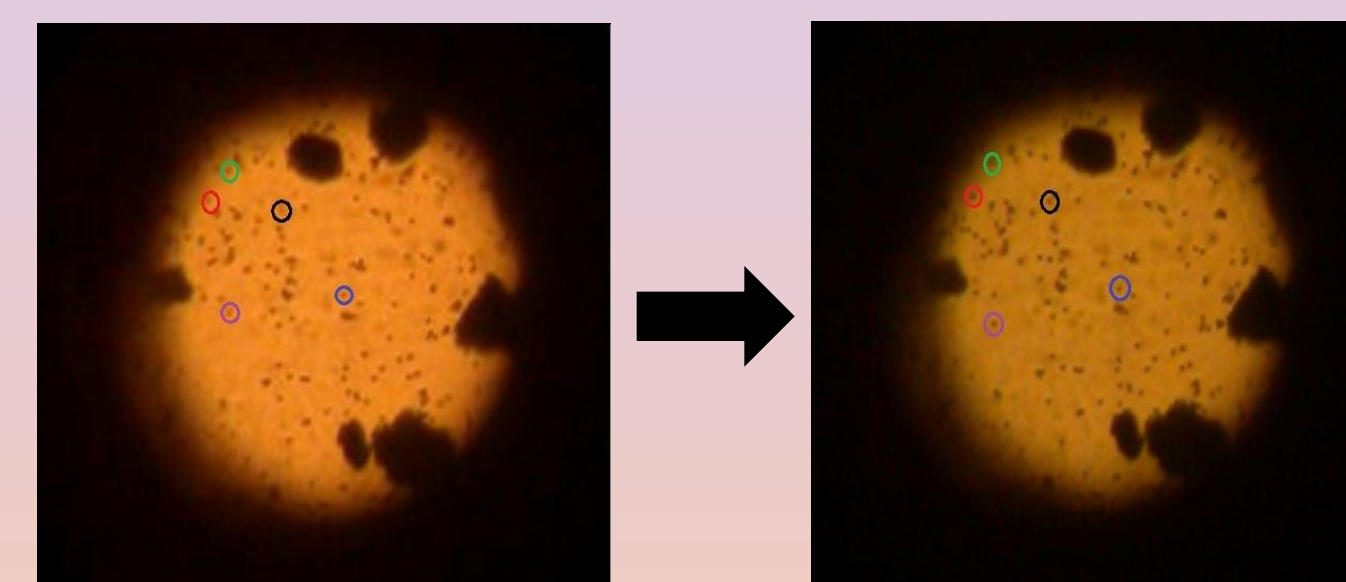
4:1 Meth-Ethanol



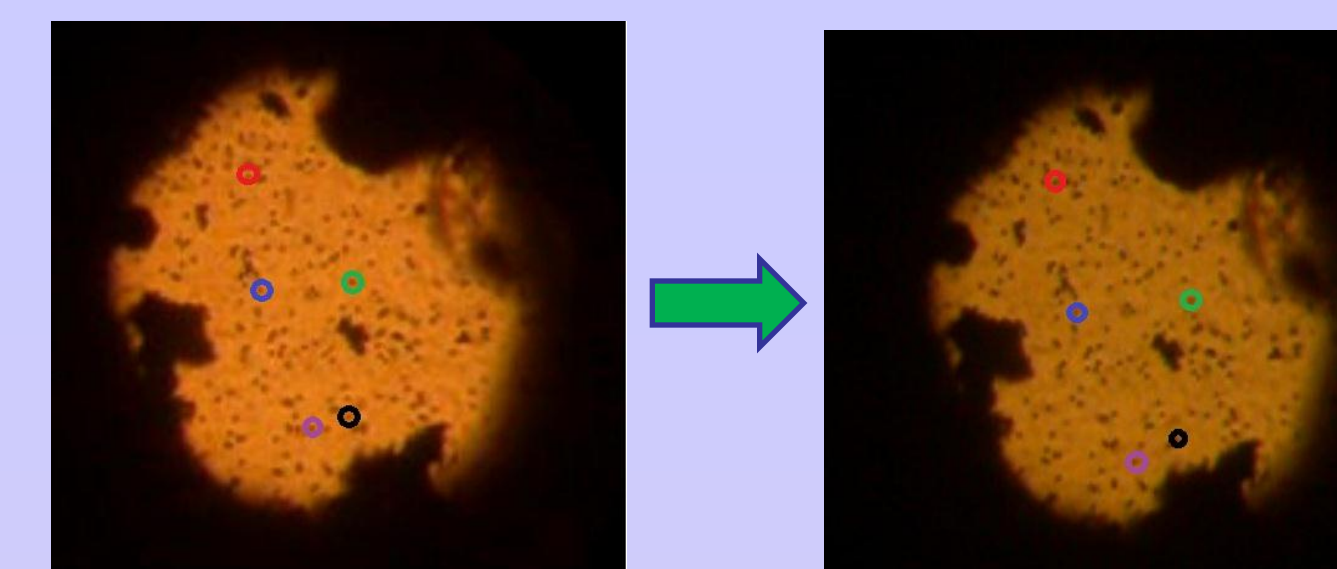
Water



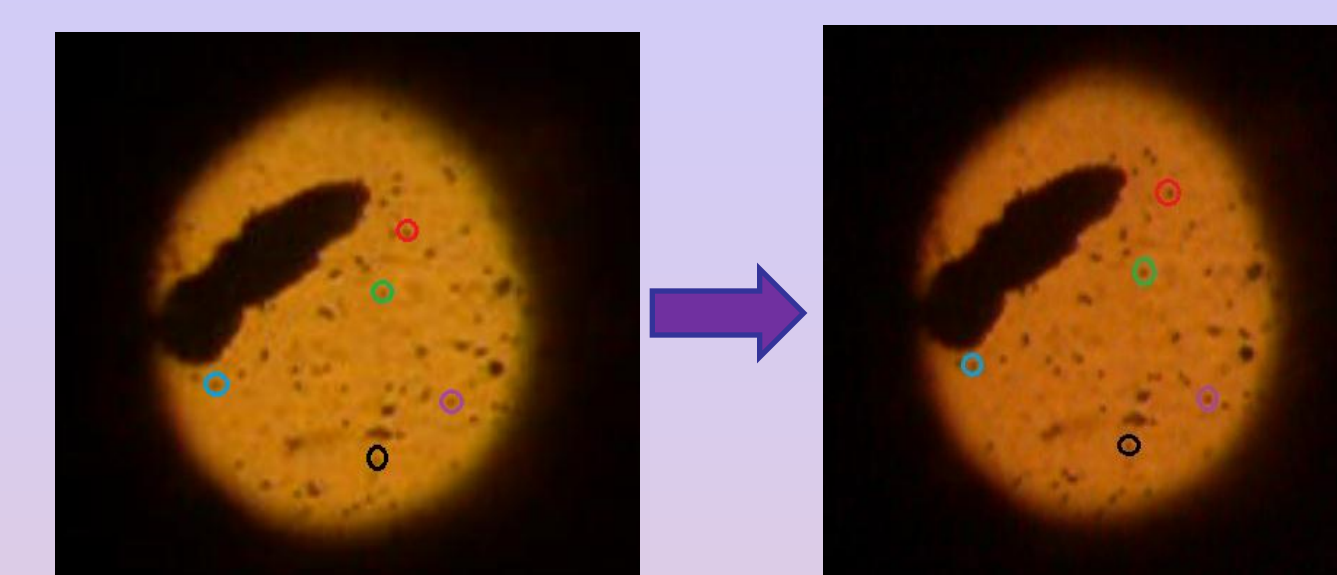
2-Isopropanol



Methanol



Ethanol



In the images shown, the first and last frames display the position of the particles along their mean squared displacement. The same particles are the same color in either frame. The motion is not shown in the still frames but greater displacement can be expected in the less viscous fluids (4:1 and Methanol) than in the more viscous fluids (Ethanol and 2-Isopropanol).