The difference between microscopic viscosity and macroscopic viscosity of crystal-bearing magmas

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Magma is a mixture of silicate melts, crystals and bubbles. The amount of crystal and bubble particles in magmas significantly affects its viscosity, which increases dramatically as particle volume fraction increases. Viscosity estimation of magmas is important when we understand the time and space scales of volcanic activities, hence viscosity measurements in analogue experiments and melting experiments were actively conducted. We propose that multi-phase fluids like magmas have two different, apparent viscosities. One is defined as “microscopic viscosity”. It appears when micro objects like crystals move in a magma chamber. The other is defined as “macroscopic viscosity”. It is a bulk viscosity, and appears when a magma rises in the volcanic conduit. In previous analogue experiments for solid-liquid fluids, falling-ball viscometry [1] is considered to measure microscopic viscosity and a rotational viscometer [2] is considered to measure macroscopic viscosity. However, in previous researches, there was no experiment that compares viscosities obtained by these two different methods. Therefore, this study was performed to clarify the differences between microscopic viscosity and macroscopic viscosity by measuring viscosities of one solid-liquid fluid by falling-ball viscometry and with a rotational viscometer.
Material and Experimental Technique: Suspensions of plastic beads of two different radius (0.75mm, 1.5mm with density=930kg/m^3) immersed in corn syrup (Karo corn syrup with density=1400kg/m^3 and viscosity η~7 Pa･s at 23℃) were used as analogues of crystal-bearing magmas. We prepared ten different suspensions by changing particle radius (0.75mm,1.5mm) and particle volume fractions (F_p =0,5,10,20,30%). Microscopic viscosity was measured by falling stainless steel balls of three different radius (0.75mm with density=9620kg/m^3 , 2.5mm with density=7960kg/m^3, 4.76mm with density=7950kg/m^3) into a 100ml, φ51mm glass beaker filled with the magma analogue. Macroscopic viscosity was measured using a coaxial double cylinder rotational viscometer that is of Kawanami’s own making. We changed the voltage (1.0V, 1.5V, 3.0V) applied to the motor, to investigate the shear thinning behavior.
Results: We used the viscosities measured with a rotational viscometer driven by 1V as representative macroscopic viscosities, because the effect of shere thinning looks low enough. At R_{susp}=0.75mm, where R_{susp} is the radius of the suspended particles, the ratio of values of microscopic viscosity to those of macroscopic viscosity, $\eta_{micro}/\eta_{macro}$, were about 0.7~0.9 under the conditions that R_{fall}/R_{susp} is 1.0 or 3.3, where R_{fall} is the radius of the falling ball, and F_p is less than 20%. Moreover, it is suggested that $\eta_{micro}/\eta_{macro}$ is almost 1 under the condition that R_{fall}/R_{susp} is 6.4 and F_p is less than 30%. At R_{susp}=1.5mm, $\eta_{micro}/\eta_{macro}$ is ranging from 0.6 to 0.9 under the conditions that R_{fall}/R_{susp} is 0.5. 1.7, or 3.2 and F_p is less than 20%.

Reference

[1]Milliken WJ et al. (1989) Physicochem Hydrodynam, 11(3), 341-355.
[2]Gaudio PD et al. (2013) Geochemistry Geophysics Geosystems, 14(8), 2661-2669.

