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Viscosity and Thermal Conductivity of Stable Graphite Suspension Near Percolation

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Abstract:

Nanofluids have received much attention due, in part, to the range of properties possible with different combinations of nanoparticles and base fluids. In this report, we measure the viscosity and thermal conductivity of suspensions of graphite particles in ethylene glycol as a function of volume fraction. Above the percolation threshold, the slope the thermal conductivity enhancement reduces, while that of the viscosity enhancement increases. These results provide insight into the mechanisms behind the variable viscosity.

Keywords: percolation, viscosity, shear thinning, graphite suspensions

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Introduction

Colloidal solutions with nanoparticles, also called nanofluids,[1] have attracted extensive attention due to their abnormal thermal conductivity enhancement and the potential applications in energy engineering area.[2-5] The mechanisms of heat conduction in nanofluids have been extensively studied and debated.[6-13] Below the percolation threshold, the thermal conductivity increases faster than above the percolation threshold, contrary to electrical conductivity, and explained the phenomena based on the interfacial energy of clusters before and after percolation. Viscosity of nanofluids/suspension is another important parameter for practical applications, especially for flow application.[14-20] However, there were no studies on the percolation behavior of viscosity. In this work, we measure the thermal conductivity and viscosity of graphite suspensions as a function of volume fraction, focusing on the percolation behavior. We observe different trends for thermal conductivity and viscosity near the percolation region.

1. Experimental Details

Graphite flakes are first prepared by sulphuric acid intercalation and microwave expansion which exfoliates the natural graphite into graphite flakes.[21, 22-24] The graphite flakes are then mixed with ethylene glycol. The solutions are ultrasonicated for 35 min to disperse the particles and form stable graphite suspensions. Solutions of different volume fraction are prepared by diluting the concentrated 1 vol. % suspension. SEM images show the morphology of the graphite flakes (see Fig. 1(a)). The individual graphite particles have diameters ~5 μm, but, as can be observed in the optical microscope image in Fig. 1(b), the flakes form much larger clusters. The clusters are isolated from each other when the graphite volume fraction is low (typically less than 0.07 -0.08vol.%), and merge to form percolation network when the graphite volume fraction is high (typically higher than 0.1 vol.%).[21, 25] Our previous studies established that such nanofluids have a percolation threshold at 0.07% volume fraction.

3. Results and Discussion

The dynamic viscosity of the graphite suspensions, measured using a cone-plate setup, is shown in Fig. 2 at room temperature. Two key results are evident in this figure. First, the graphite suspension shows clearly non-Newtonian behavior. Specifically the viscosity decreases with increasing shear rate (i.e. shear thinning), especially for high volume fraction. This is likely due to the graphite flakes realigning themselves along the flow direction under the application of shear stress. This reorganization reduces the fluid resistance to the shear flow and, thus, reduces the viscosity. Second, the viscosity of graphite suspension increases as the volume fraction increases.

To better understand how the viscosity varies near the percolation threshold, Fig. 3(a) shows the viscosity enhancements of the graphite suspensions at fixed shear rates near the percolation regime. In our previous paper,[21] we observed that the thermal conductivity of graphite suspensions increases more rapidly before percolation than after percolation. Figure 3b shows new measurements using samples prepared under similar conditions with different ultrasonication time (35 min). Note that below the percolation threshold, the thermal conductivity increases faster than above the percolation threshold. Through AC impedance spectroscopy studies, we had established before that is because of tighter contact between graphite flakes below the percolation threshold, caused by energy minimization of isolated graphite clusters.[21] Contrary to the thermal conductivity, the viscosity of graphite suspension increases much faster after percolation than before percolation as shown in Fig. 3a. The viscosity behavior is similar to electrical conductivity while opposite to that of the thermal conductivity.[21] This is likely due to the fact that below percolation threshold, the graphite clusters are isolated and hence the viscosity is mostly determined by the solvent. At high volume fraction, shear stress breaks the bonds among clusters and flakes, and hence showing shear thinning behavior.

Conclusion

In this paper, we analyzed the percolation point properties for thermal conductivity and viscosity of stable graphite suspension. Opposite to thermal percolation, for viscosity, the slope above percolation increases slower than after percolation point. These results provide insight into the mechanisms behind the variable viscosity.

Acknowledgments

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References and Notes

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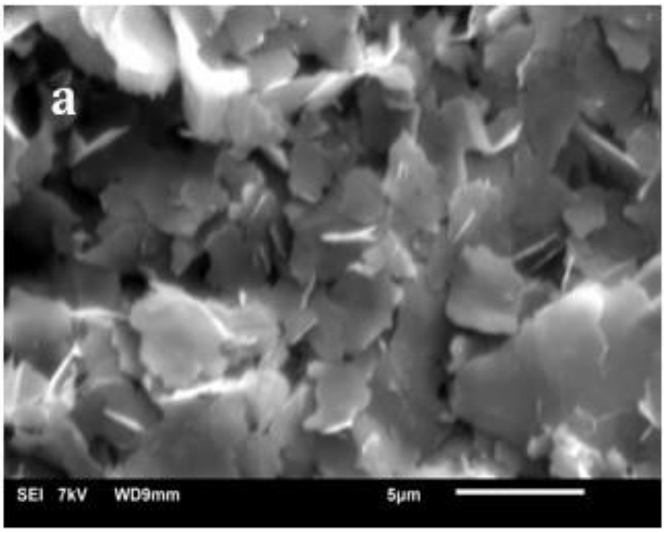
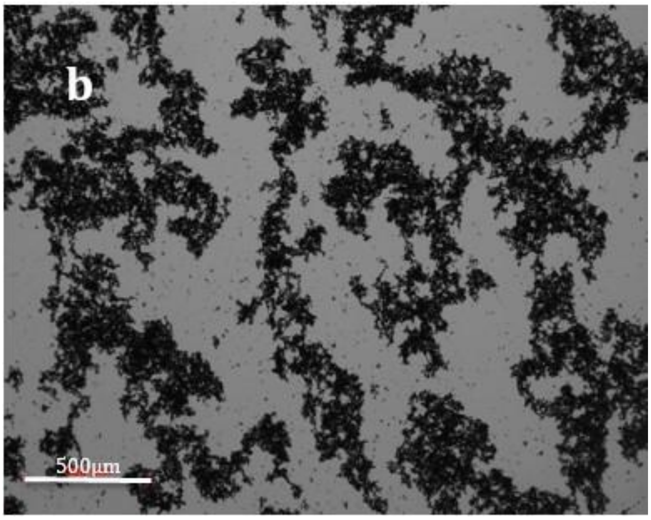
Figure captions

Figure 1. Micrographs of graphite flakes. (a) SEM image of graphite flakes （b）Optical picture of suspension with volume fraction 0.15%

Figure 2. Dynamic viscosity of graphite-ethylene glycol suspension with different volume fraction as a function of shear rate. Non-Newtonian behavior (shear thinning) begins to dominate as the graphite volume fraction increases.

Figure 3. (a) Viscosity enhancement of graphite suspension as a function of volume fraction near percolation regime at given shear rates. (b) Thermal conductivity enhancement of graphite suspension as a function of volume fraction near percolation regime.





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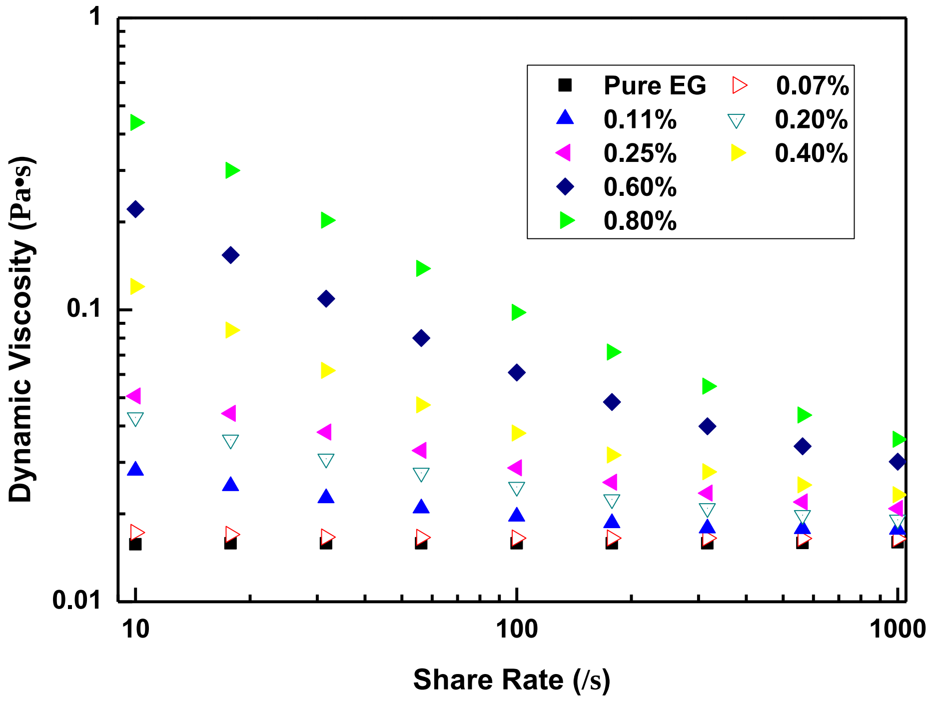

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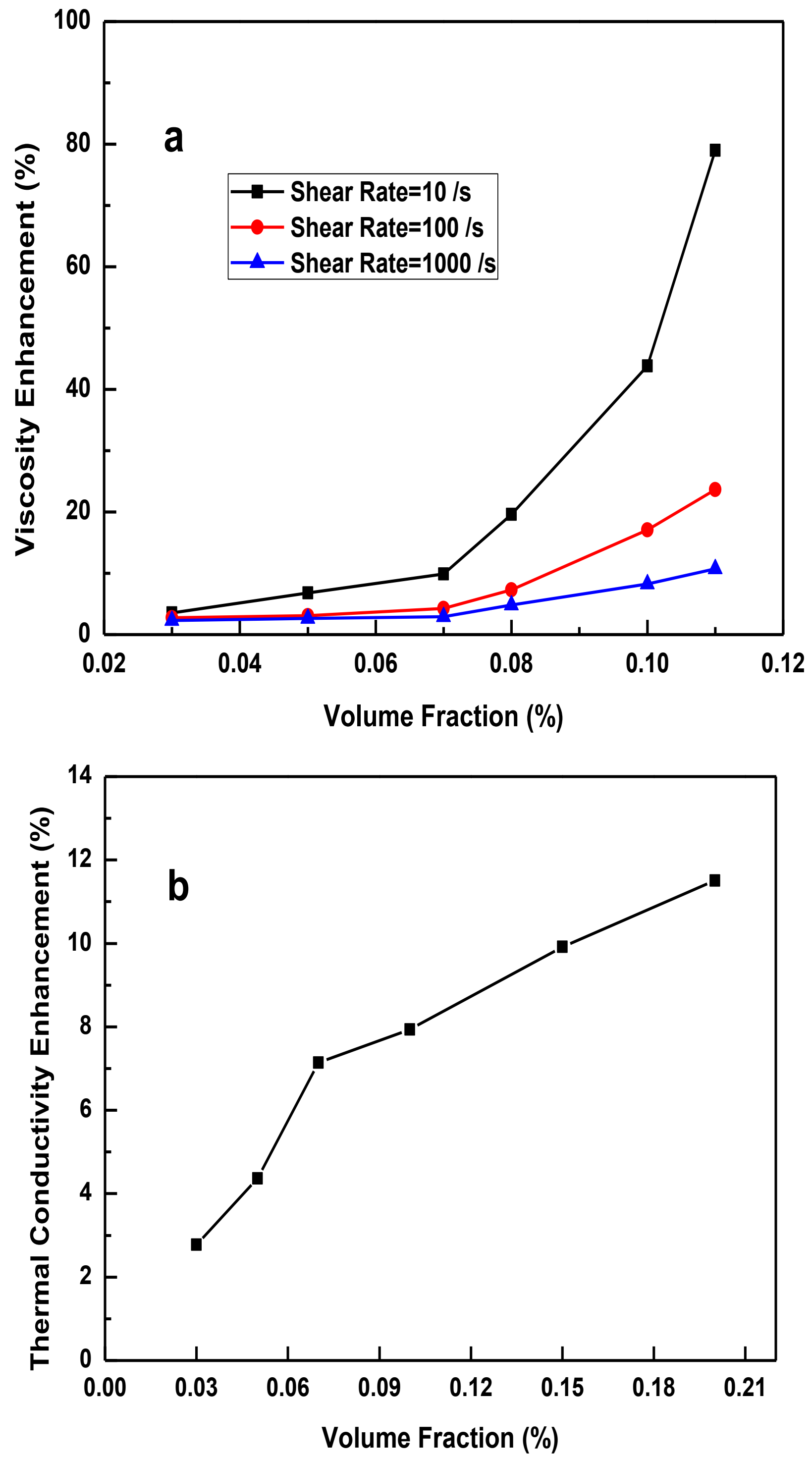

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