Introduction:
Ionanofluids are ionic liquid nanofluids. Ionic liquids are able to maintain stable dispersions of carbon nanotubes (CNTs). It has been predicted that nanofluids with very low concentrations of CNTs (~1%) have significantly enhanced thermal and electrical conductivities over their unaltered solvents [1,2,3]. This is because of the high intrinsic thermal and electrical conductivity of CNTs. Only a few investigations have been published, and of these very few study ionanofluids with CNT concentrations beyond 1 wt%. The purpose of this study is to investigate the thermal and electrical conductivities of such ionanofluids above 1 wt% CNTs.

At a high CNT concentration, we expect the CNTs to percolate, forming clusters of CNTs that are connected at long-range. These connections form continuous paths for electron transport, bypassing the bulk fluid and greatly enhancing electrical conductivity [3]. We also expect an increase in thermal conductivity; however it is unknown whether percolation is a significant factor.

Experimental:
The ionanofluids 1-methyl-3-propylimidazolium iodide (PMII), 1-butyl-3-methylimidazolium hexafluorophosphate ([bmim][PF₆]), and 1-butyl-3-methylimidazolium hydrogen sulfate ([bmim][HSO₄]) were selected for this study. After adding CNTs, each sample was heated to 60°C, stirred for 15 minutes, ultrasonicated for 40 minutes, then stirred for another 15 minutes. Samples for thermal conductivity measurements were also dried at 60°C under vacuum (~10 kPa) for 24 hours.

Impedance spectra of the CNT nanofluids were acquired using a CH Instruments 660D Potentiostat from 10⁻² to 10⁶ Hz with 40 mV amplitude and 180 seconds of preconditioning at 0V. For each measurement, the sample was contained in a 3-electrode cell with identical 1.5mm diameter Pt electrodes and submerged in a room temperature (21°C) water bath. DC conductivity was measured by applying a 1V constant potential.

Impedance spectra for PMII were taken at 25 concentrations of CNTs, from 0 to 10 wt%. CNTs were added incrementally until the viscosity of the sample made it impossible to continue. This was repeated for DMSO, a nonionic organic solvent for comparison.

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Thermal conductivity was measured using a ThermTest Inc. TPS 2500S Hot Disk Thermal Constants Analyzer. The measurement principle was based on the transient plane source method. The sensing disk was 2 mm in diameter. The sensing disk containing a heating element and a thermoresistor was inserted vertically into the sample to minimize the possibility of inducing convection.

The thermal conductivity of each ionic liquid was measured with no CNTs, 0.5 wt% CNTs, and at a concentration past the percolation threshold (~9 wt%). Percolation was confirmed via impedance spectroscopy.

Results:
The DC conductivity of PMII increased with CNT concentration as shown in figure 1. At around 8 wt%, the electrical conductivity begins to increase rapidly. At low frequencies past 8 wt%, the AC impedance response becomes flat, resembling a resistor. This indicates that there is percolation of the CNTs at this point. A change in the shape of the Nyquist plot further supports this conclusion.

The DMSO nanofluid also had a percolation threshold at around 9 wt%.

Conclusions:
The percolation threshold for PMII, [bmim][PF₆], and [bmim][HSO₄] is around 9 wt% CNTs. There is a sharp change in the shape of the Nyquist plots before and after this point. The thermal conductivity increases when CNTs are added. More data is needed to determine whether percolation causes a sharp increase in thermal conductivity.

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References: