Physical Properties of Environmental Sensing Device Fluids

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Introduction

Low-viscosity silicone oils (polydimethylsiloxane, PDMS) are used as damping fluids in a variety of environmental sensing devices (ESDs). The behaviors of these devices are strongly dependent on the material properties of the fluid such as the density and viscosity. Some of these properties change significantly over the temperature range in which ESDs are expected to perform and due to blending of multiple oils. Therefore, a better characterization of the material properties as they change with temperature is desired. Options for alternative oils to PDMS are also being considered for damping fluids; these liquids also require characterization and comparison to legacy materials.

Density, viscosity, thermal conductivity, and specific heat measurements of PDMS fluids are measured over a wide temperature range (-40 °C to 150 °C) and a range of blends. These properties are compared to the properties of alternative liquids which have even more drastic variations with temperature. These measurements will then be used to more accurately model ESD performance in realistic operating temperatures. A subset of these results has been published in an available report [1].

Measurements of viscosity were made using three methods:

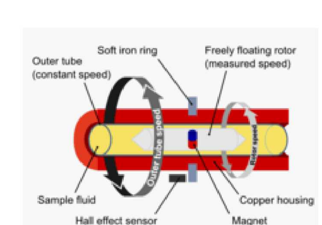
Capillary Viscometer

Difficult T control, One shear rate, 0.5% precision

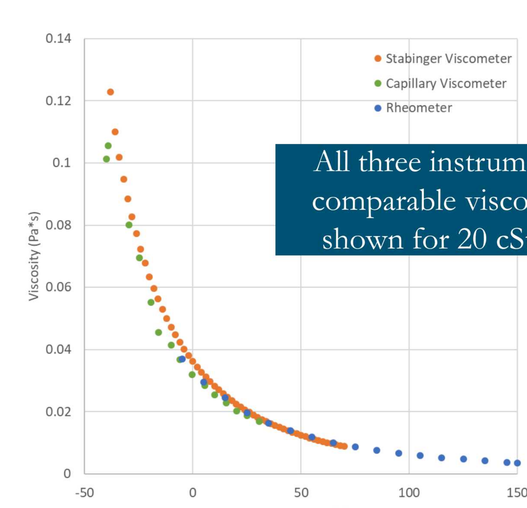
Rheometer

Range of temperatures, shear rates, 2-5% precision

Stabinger Viscometer

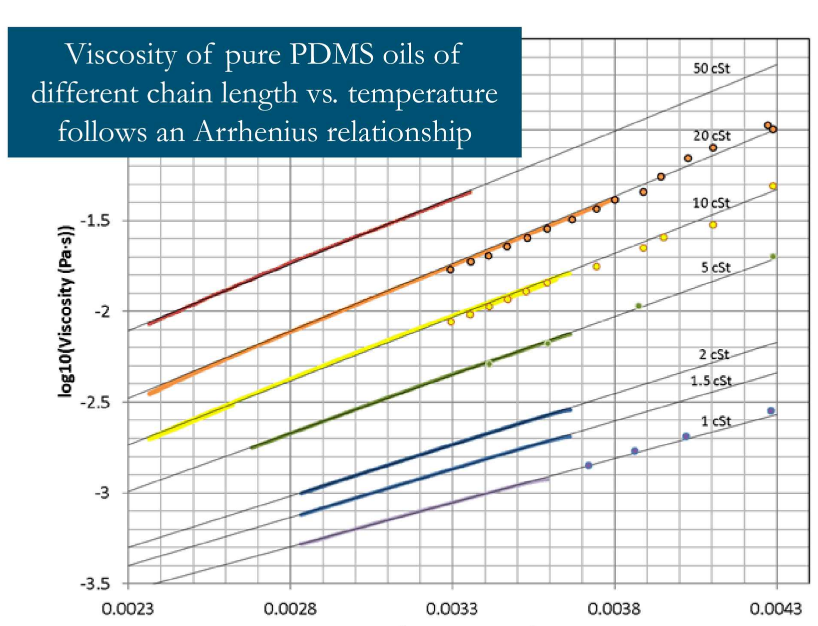


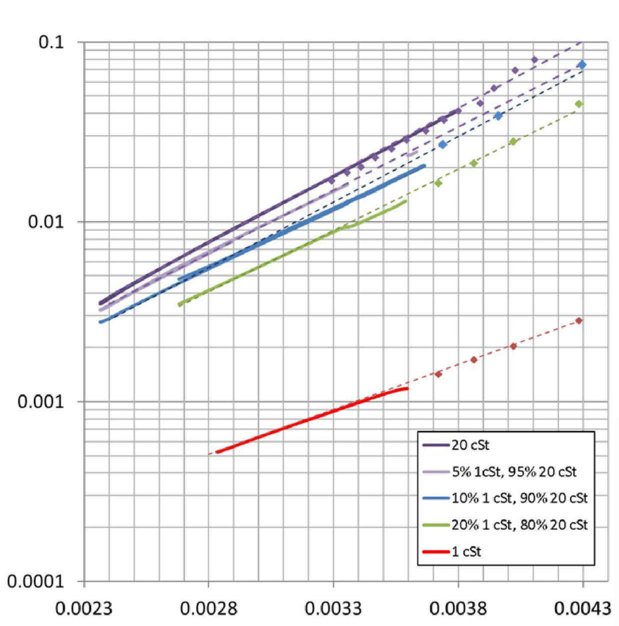
-70 C to 100 C, one shear rate, 0.5% precision

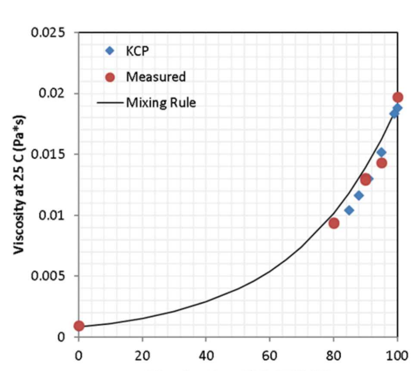


All three instruments give comparable viscosity data, shown for 20 cSt PDMS

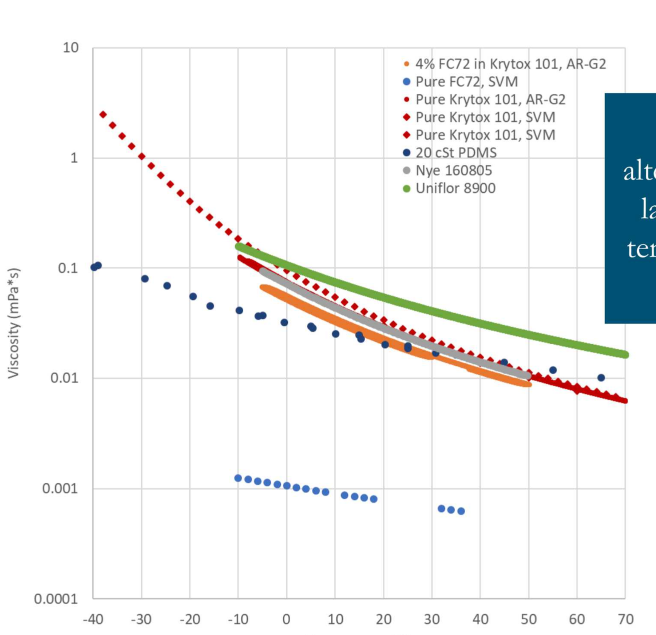
Viscosity of pure PDMS oils of different chain length vs. temperature follows an Arrhenius relationship





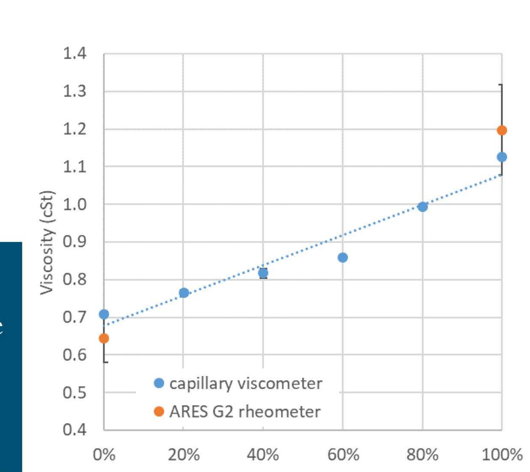


Blends of PDMS fluids approximately follow a simple mixing rule. Viscosity measurements made at SNL match those made at KCNSC



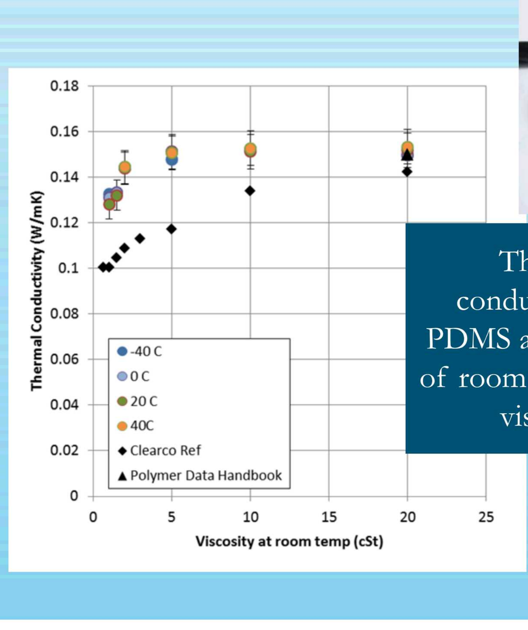
The viscosity of alternative oils have much larger dependencies on temperature as compared to PDMS

For surveillance activities, measurements of viscosity can be made on small volumes of fluid. These measurements were made on fluid volumes as low as 1.5 mL using a specialized capillary viscometer at 25 °C.



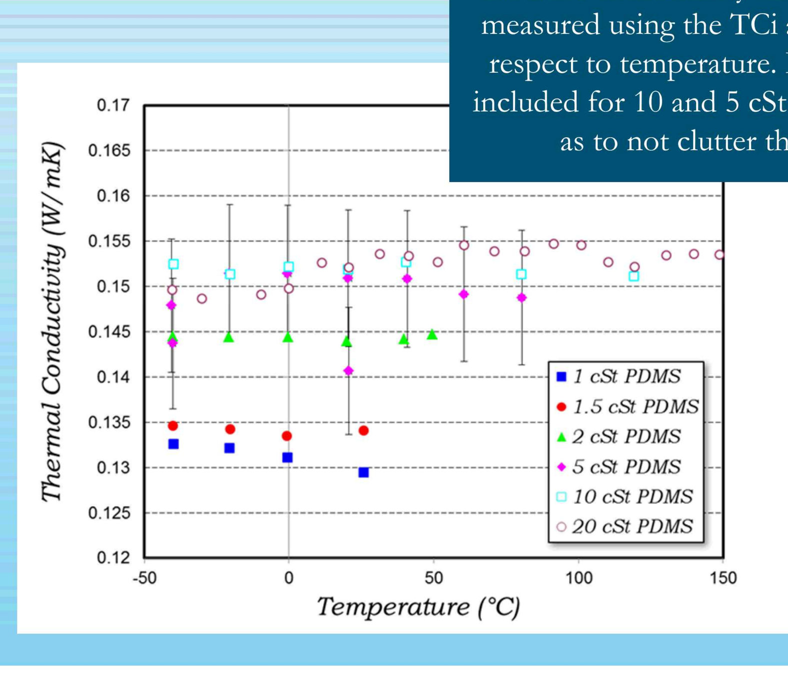
Thermal Conductivity

TCi C-Therm planar source thermal conductivity probe and a ThermTest transient hot wire liquid thermal conductivity meters were used to measure the thermal conductivity of fluids to an accuracy of +/- 5%. Within the expected error, the thermal conductivity of each of the liquids is not a function of temperature within the range of temperatures studied.



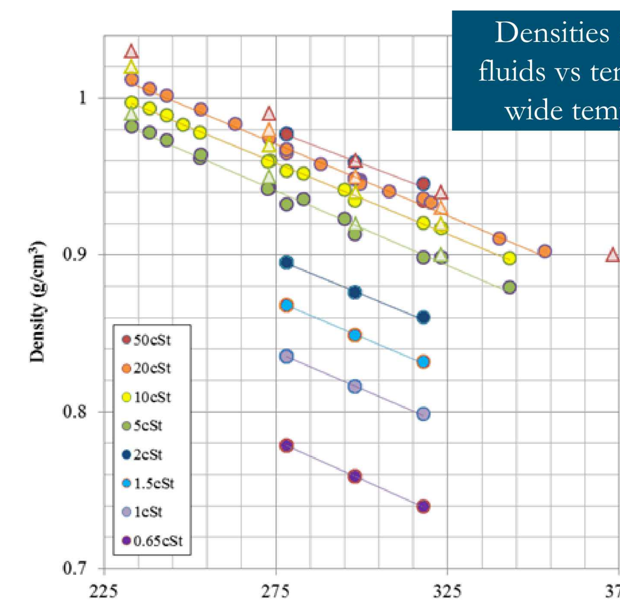
Thermal conductivity of PDMS as a function of room temperature viscosity

Thermal conductivity of PDMS liquids measured using the TCi apparatus with respect to temperature. Error bars are included for 10 and 5 cSt PDMS only so as to not clutter the graph.

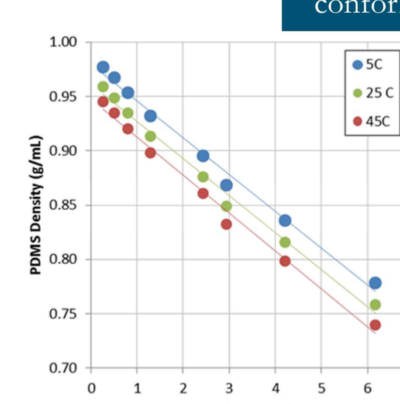


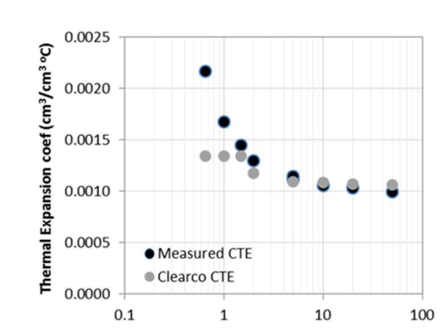
Density of fluids were measured using three separate methods. A Mettler Toledo DE40 oscillating U-tube density meter. Assuming a perfectly clean U-tube, this apparatus has a reported accuracy of 1x10[-4] g/cm[3] reported accuracy, but was only able to deliver density measurements between 5 °C – 50 °C. A Density measurements outside of the 5 °C – 50 °C temperature range were obtained using a 250 mL Le Chatelier type pycnometer or the Stabinger viscometer which also has a U-tube density measurement capability.

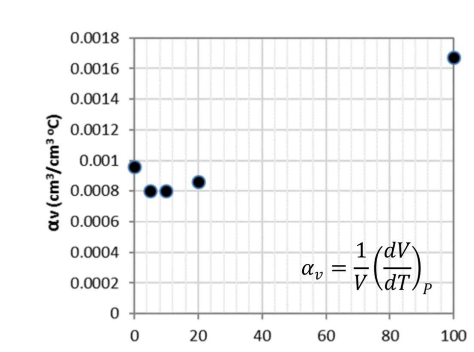
Densities of pure PDMS fluids vs temperature over a wide temperature range



Density as a function of inverse molecular weight. As the polymer chain length increases, the density also increases due to decreased conformational degrees of freedom



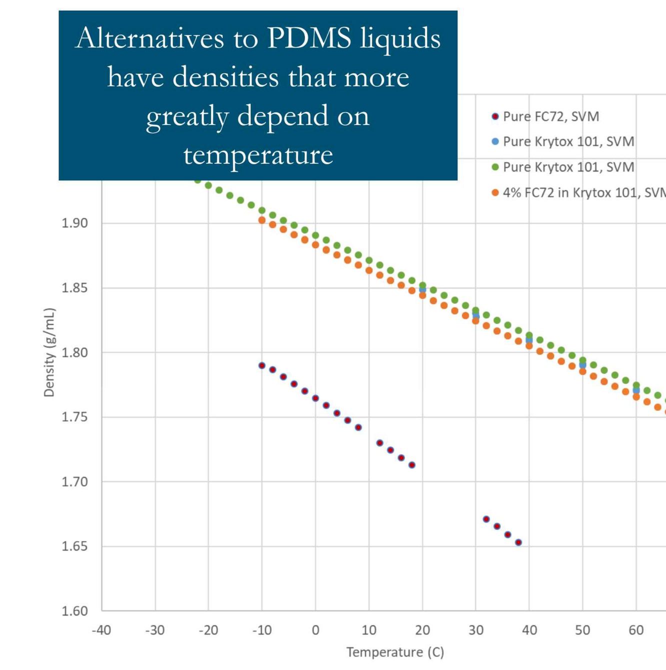




$$\alpha_v = \frac{1}{V}\left(\frac{dV}{dT}\right)_P$$

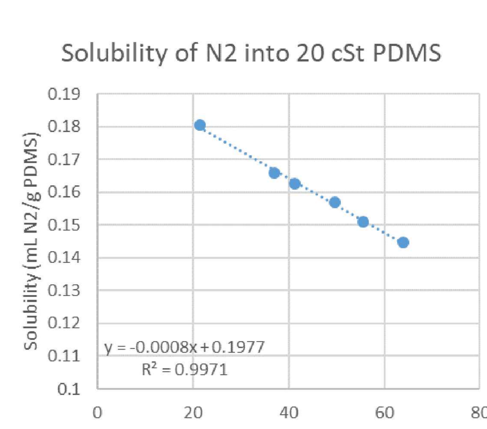
The coefficient of thermal expansion for PDMS liquids was measured vs. molecular weight for pure liquids and also for mixtures between 20 cSt and 1 cSt

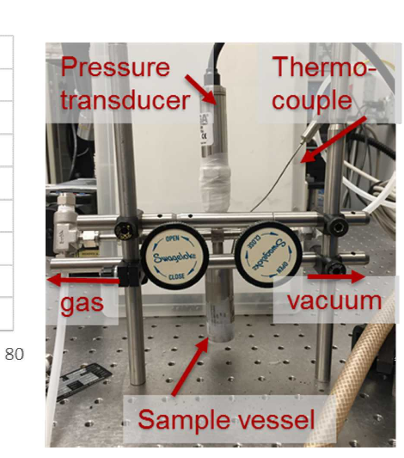
Alternatives to PDMS liquids have densities that more greatly depend on temperature



Solubility of Gasses

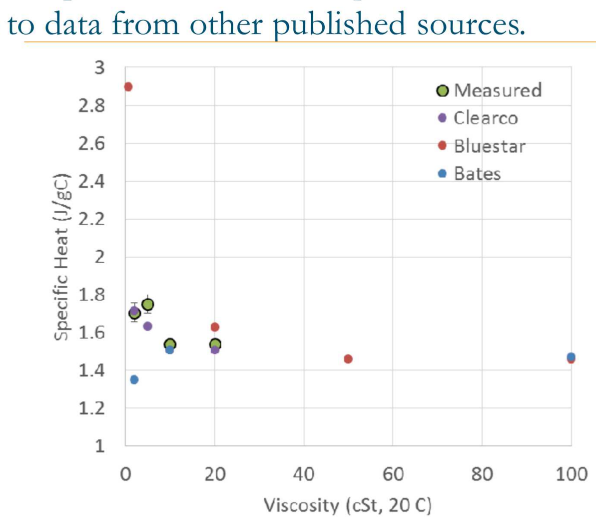
A simple device was created to measure the solubility of gasses in liquids. A sample vessel is filled partially with degassed fluid that has been maintained within an evacuated desiccator vessel for weeks. A vacuum is pulled on the sample and the pressure is monitored over days until it becomes stable at the vapor pressure of the fluid. Then gas is introduced to the sample chamber to pressurize the system to a predetermined value. As the gas dissolves into the sample fluid, the pressure and temperature are measured over time using a thermocouple and pressure transducer.

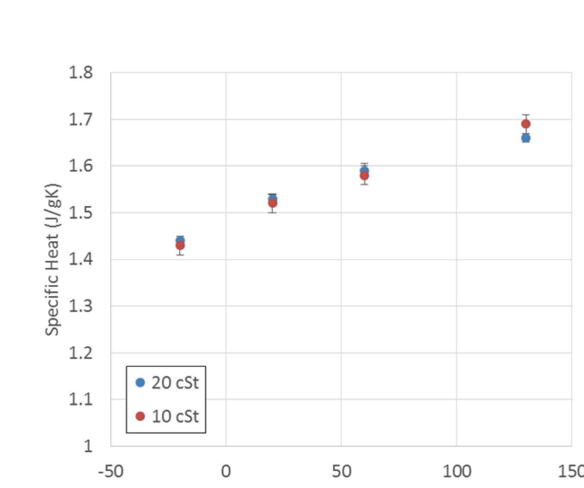




Specific Heat

The heat capacities of PDMS liquids were measured using a differential scanning calorimeter and are shown with respect to data from other published sources.





Conclusions

A suite of physical property measurements have been demonstrated on materials that are candidate liquids for use in environmental sensing devices and rolamites. PDMS oils have advantages in that many of their physical properties do not depend greatly on temperature as compared to other candidate lubricants. These measurements will be useful for predicting device performance at various temperatures using computational models and may also aid in the design choice of blend composition or oil type.

References

C. C. Roberts, A. Graham, M. Nemer, L. Phinney, R. Garcia, E. Stirrup, “Physical Properties of Low-Molecular Weight Polydimethylsiloxane Fluids”, SAND2017-1242, Sandia National Laboratories, 2017.

Acknowledgements

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