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Optical Response and Hugoniot State of Shock-Compressed Heavy Liquids

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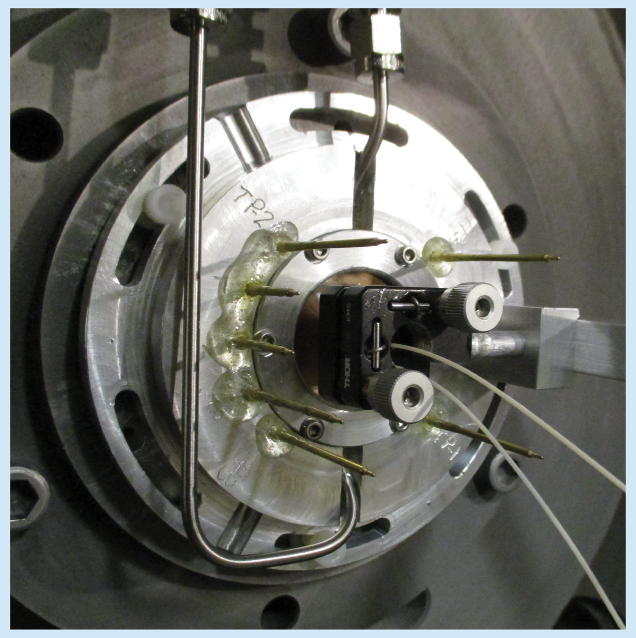
Overview

The shock response of heavy liquids was tested in a gas gun to determine index of refraction and Hugoniot equation of state data. Materials tested include:

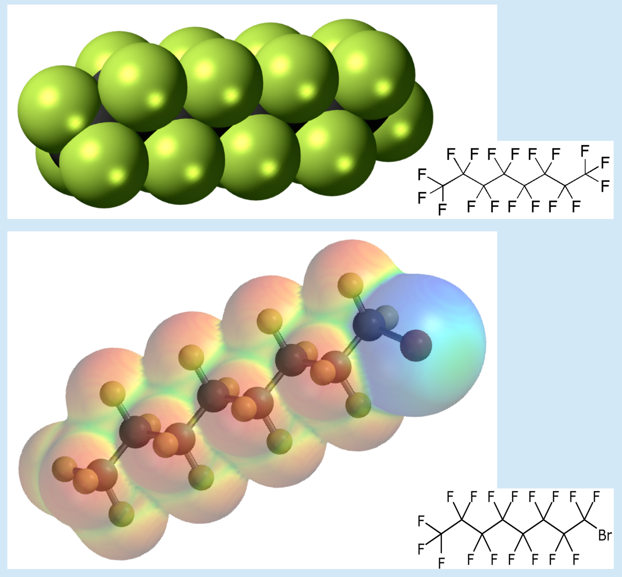
- Perfluorooctane (PFO)
- Perflubron (PFB)
- Sodium polytungstate (SPT) + deuterium oxide (D_2O)
- Lithium heteropolytungstate (LST) + D_2O

Materials were subjected to one-dimensional compression from a copper impactor and driver, and Photonic Doppler Velocimetry (PDV) was used to measure shock and particle velocity through the liquid cell at pressures between 6.1 and 10.6 GPa.

SPT and LST are adjustable density solutions up to ~3 g/cm^3 and have low toxicity, and can be used as impedance-matched window materials for equation of state experiments[1]. These four heavy liquids are good candidates for tamped Richtmyer–Meshkov Instability (RMI) experiments to interrogate dynamic interface instabilities at non-zero pressure.



Gas Gun Target Photo



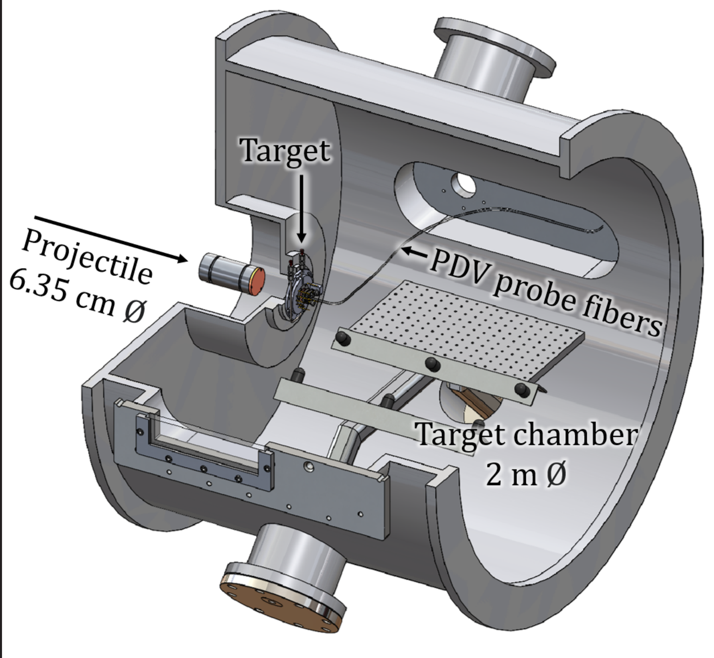
Perfluorooctane and Perflubron Models[2]

Gas Gun Setup

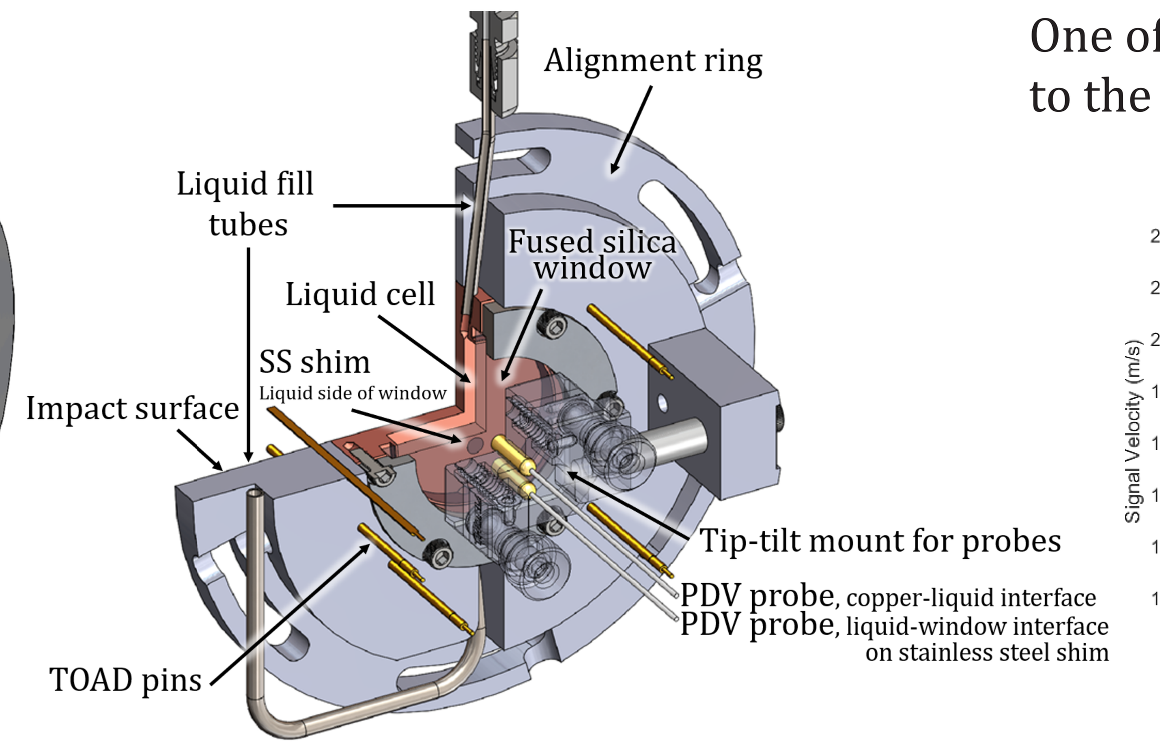
Impact experiments were conducted using a single-stage gas gun with an 18 m long barrel and 6.35 cm diameter projectile, which carried a 6 mm thick copper impactor. The heavy liquid material is confined inside a copper cell, which is capped with a fused silica window. Projectile impact at 1.3 km/s sends a one-dimensional shock through the heavy liquid material.

Diagnostics:

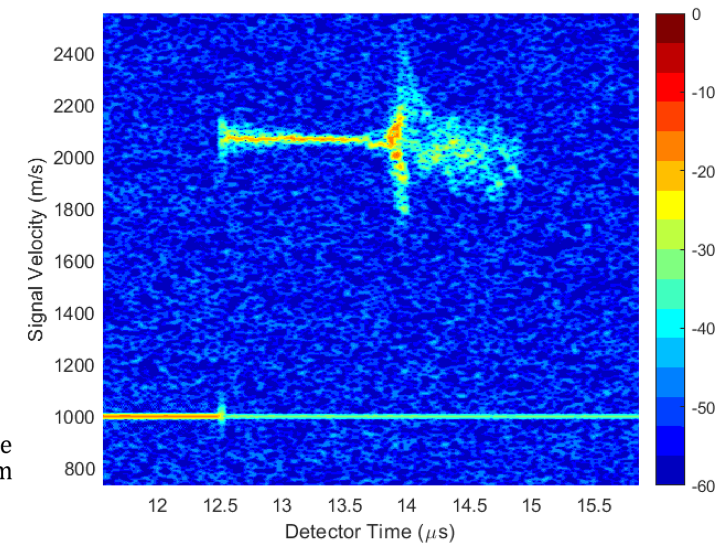
- Time of arrival detector (TOAD) pins for impact velocity, timing, and tilt
- 2 PDV probes at 1550 nm:
  One reflecting off the copper-liquid interface (P1)
  One off a stainless steel shim glued to the liquid-window interface (P2).



Gas Gun Target Chamber



Liquid Target Assembly

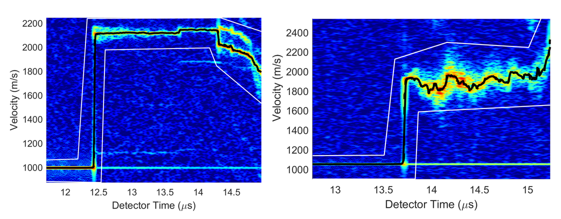


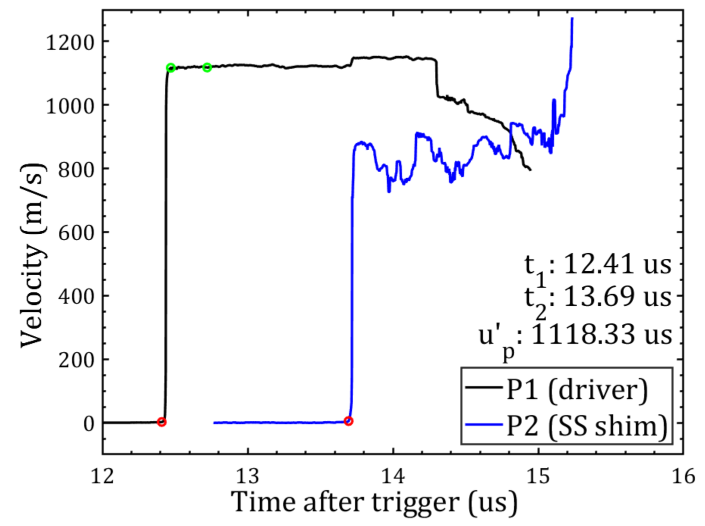
PDV Spectrogram - SPT P1

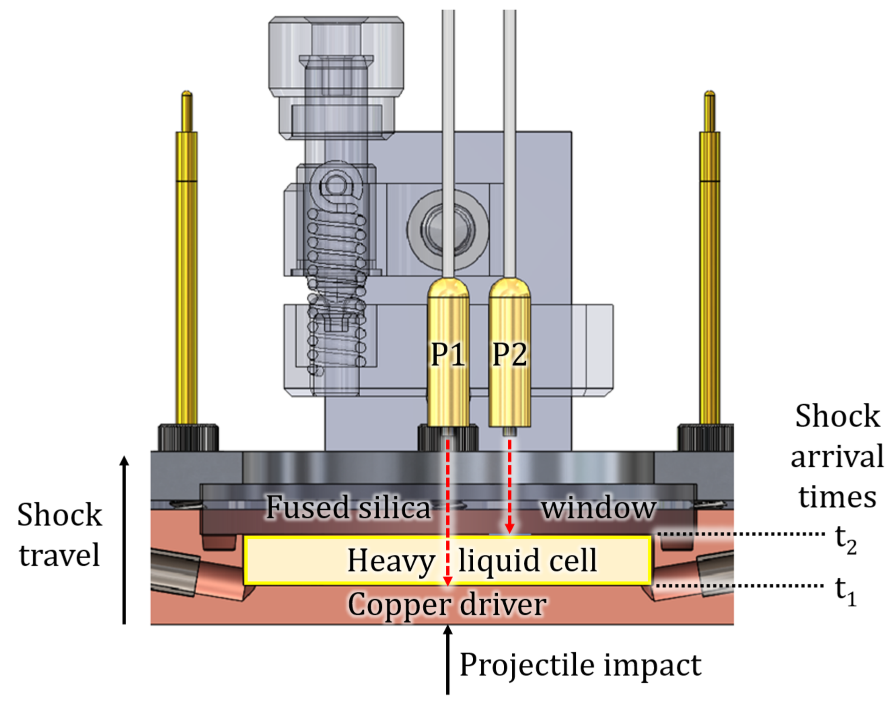
Shock Hugoniot and Index of Refraction Data

Hugoniot properties of the heavy liquid materials can be calculated from the measured impact velocity (U_p), shock velocity (U_s), and impedence matching at the copper-liquid interface.

Spectrograms of the PDV signals reduced (PFB)







U_s = shock speed through liquid = liquid cell depth / (t_2 - t_1)
u_p = calculated heavy liquid particle velocity using impedence matching
u'_p = measured heavy liquid particle velocity from PDV P1

Difference in calculated and measured particle velocities can be used to calculate shocked index of refraction using[3]:

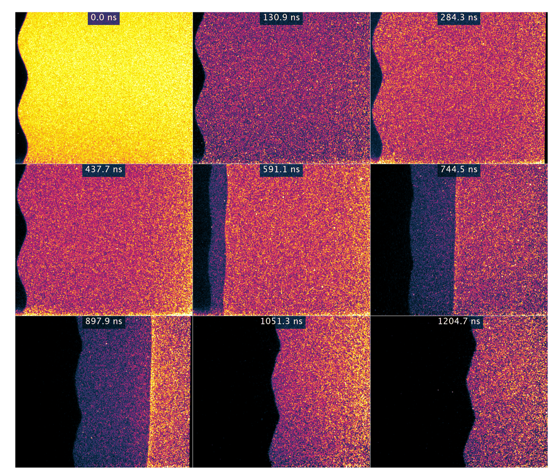
$$n = \frac{n_0 U_S - u'_p}{U_S - u_p}$$

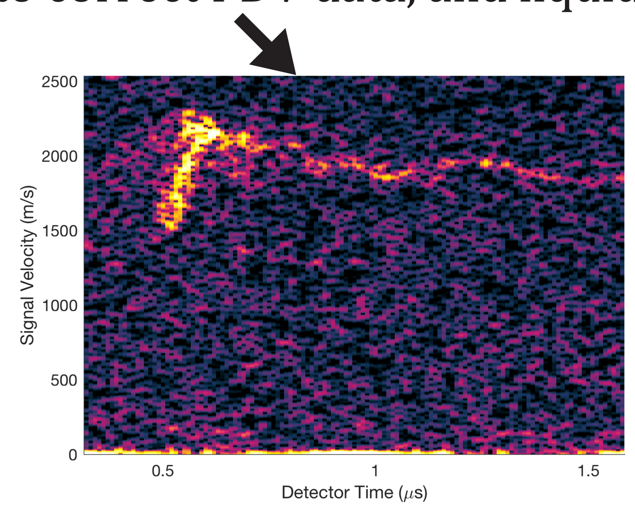
Examples:
PFB: n_0 = 1.305 n = 1.476
SPT: n_0 = 1.565 n = 1.782

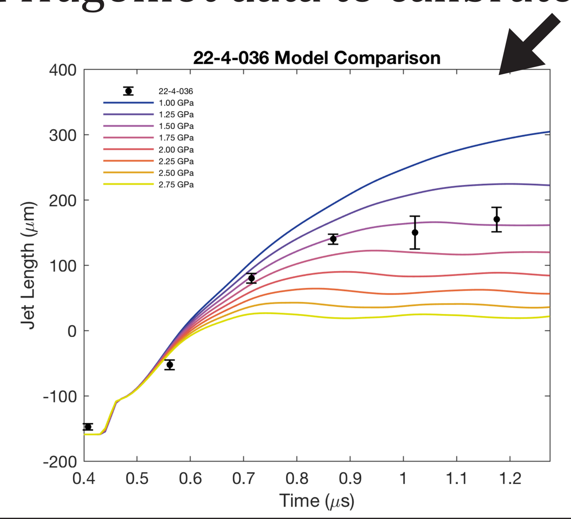
Material	Density ρ (g/cc)	Impact vel. U_p (km/s)	Shock vel. U_S (km/s)	Calc. Particle vel. u_p (km/s)	Meas. particle vel. u'_p (km/s)	u'_p - u_p (m/s)
PFO	1.77	1.290	3.079	1.126	1.127	1
PFB	1.93	1.291	3.083	1.115	1.118	3
LST + D_2O	2.91	1.274	3.260	1.024	1.046	22
SPT + D_2O	3.01	1.284	3.460	1.013	1.056	43

RMI Radiography Application

X-ray phase contrast imaging at Argonne National Lab's Advanced Photon Source was used to interrogate RMI at non-zero pressure. A x-ray image montage, spectrogram, and model correlation plot are shown here for a PFO-tamped test with a tantalum impactor and molybdenum driver at an impact velocity of 2.326 km/s. These experiments utilize the shocked index of refraction measurements to correct PDV data, and liquid Hugoniot data to calibrate models.







Further, if material strength and optical response of these tamper liquid materials are well known, then the need for radiography can be eliminated from future experiments to allow for more flexible test platforms.

Summary

Shock impact experiments were conducted on four heavy liquid materials to obtain optical and Hugoniot data. These materials are of interest as potential impedence-matched window material for high density material Hugoniot characterization, as well as non-vacuum tampers for RMI experiments. Data obtained in these experiments provide optical transmissibility information, and material shock properties for calculations and model calibration.

References:
[1] J.L. Wise, "Refractive Index and Equation of State of a Shock-Ccompressed Aqueous Solution of Zinc Chloride", in *Shock Waves in Condensed Matter - 1983*, J.R. Asay, R.A. Graham, and G.K. Straub, Eds. Elsevier Science Publishers, 1984, pp. 317-320.
[2] "Perflubron", en.wikipedia.org. https://en.wikipedia.org/wiki/Perflubron (accessed June 30, 2022).
[3] P. Renganathan , T. S. Duffy , and Y. M. Gupta, "Hugoniot states and optical response of soda lime glass shock compressed to 120 GPa", J. Appl. Phys. 127, 2020.

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