Onedimensional isentropic compression

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ONE-DIMENSIONAL ISENTROPIC COMPRESSION

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ABSTRACT

The generation of nearly isentropic pressure-density states in a molecular fluid sample, e.g. H_2O is examined by a series of one-dimensional finite difference calculations. We employ a series of buffer materials of increasing shock impedance (Lexan, Al, Fe, W) behind the sample and impact it with a composite flyer plate of the same series of materials. In the case of H_2O impacted at 2.5 km/sec, three-fold nearly isentropic compression to a pressure of 70 GPa is achieved in 10 μsec with a 3 cm thick composite impactor.

INTRODUCTION

Dynamic pressure-density isentropic compression data can usefully supplement shock and high pressure ultrasonic, x-ray diffraction and high pressure Raman and Brillouin scattering data because they provide thermodynamic information along a unique thermodynamic path (Fig. 1). Such data may be used to develop inter-atomic and molecular potential functions for molecular media such as H_2O, CO_2, H_2 and NH_3 as well as study phase transitions.

All previous experiments and experimental concepts have achieved isentropic compression of non-electrical conductors by utilizing electrically or explosively driven converging cylindrical geometries and in many cases magnetic fields to obtain ultra high pressures within cylindrical volumes[2,3,4]. Pressures up to 800 GPa have been reported in H_2 with this configuration. The density of cylindrical samples can be obtained via flash x-ray radiography to precisions which vary from 10 to 40%. The pressure must be calculated using an assumed equation of state, or inferred from magnetic field intensity measurements[3,4].

In 1972 Kompaneets _et al._[5] proposed an experimental configuration to achieve an isentropic compression in one-dimensional planar flow which utilized a shock wave driven into a medium of initial variable porosity with a massive explosive charge. Motivated by this paper, we carried out an extensive series of one-dimensional finite-difference flow calculations[6] using an initial variable density samples. The phenomenon of a shock wave gradually transforming to a dispersed isentropic compression wave, predicted[5] was verified to a limited extent. However, because of the greater complexity of

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carrying out such experiments we chose to rather study flows induced by symmetric impact of layered geometries (Fig. 2).

CALCULATIONS

With the goal of eventually carrying out an experimentation using a propellant gun and initially carrying out experiments on water, we utilized the simplified equations of state indicated in Table 1 for our calculations. A composite impactor and target materials in the configuration of Fig. 2 comprised a sequence of materials whose impedances steadily increase from that of H_2O.

When H_2O is impacted by a composite flyer of Fig. 2 a relatively smooth build-up of pressure in the central H_2O layer results.

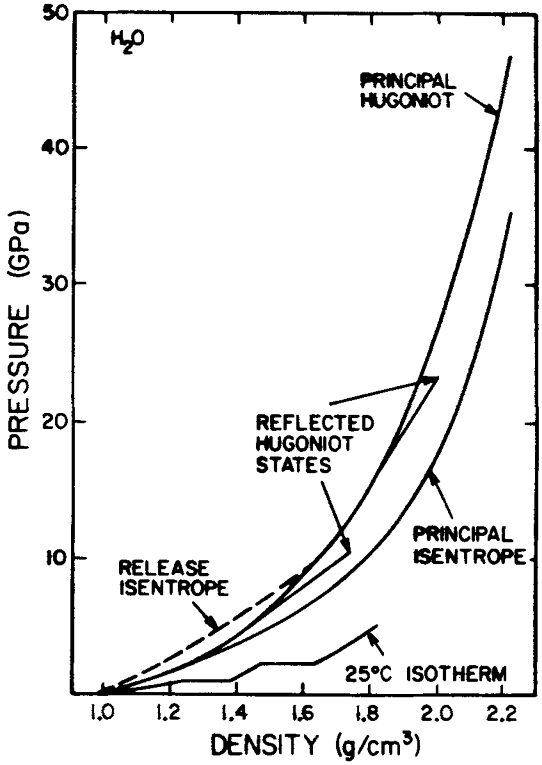

Fig. 1. Pressure-density relations for water. Horizontal portions of isotherms at 1.0 and 2.2 GPa correspond to phase transitions. Representative reflected shock state shown are typical of data now available to 220 GPa[1].

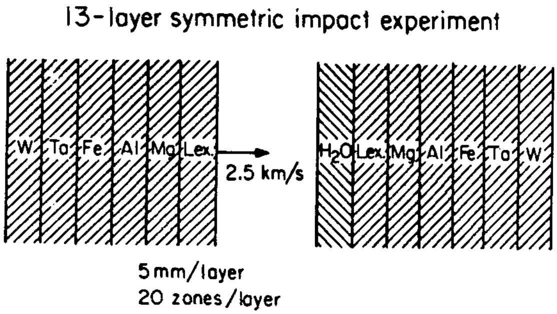

Fig. 2. Symmetric impact configuration for nearly isentropic compression of water.

Table I Assumed Hugoniot Parameters for Impact Calculations[a]

Material	$\rho_0 (g/cm^3)$	C_0 (km/s)	s	γ_0
W	19.30	4.005	1.268	1.20
Ta	16.66	3.423	1.214	1.69
Fe	7.86	3.768	1.655	1.30
Al	2.70	5.355	1.345	2.13
Mg	1.78	4.650	1.200	1.46
Lexan	1.196	2.796	1.258	2.00
H_2O	1.00	3.111	1.160	2.00

(a) data source, Reference 6

Figure 3 shows the pressure in a particular H_2O zone as a function of time from the impact. The time scale of the pressure rise is determined by the width of the material layers.

The solid curves show the theoretical Hugoniot curve and isentrope of H_2O obtained from the assumed equation-of-state properties (Table I). The H_2O pressure rises monotonically for about 10 μsec following a P-V path which is near the theoretical isentrope. In terms of pressure, the deviation from the isentrope is negligible although some shock heating is apparent from entropy calculations.

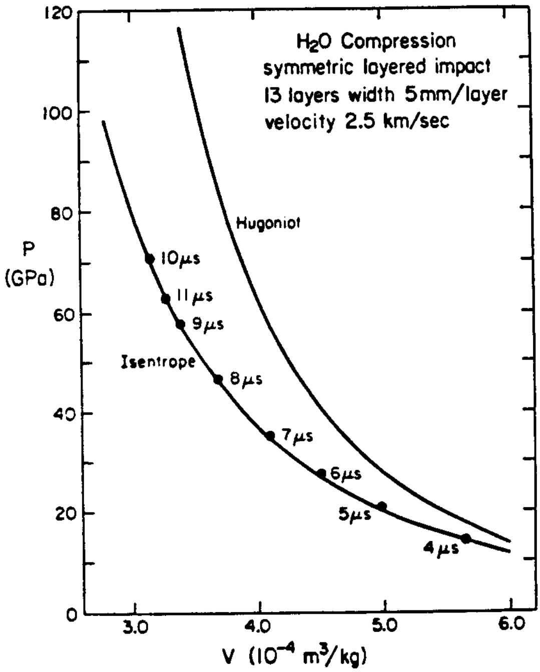

Fig. 3. Computed results of 13-layer symmetric impact. Points indicate computed pressure and specific volume within H_2O layer at the indicated times after impact. Theoretical Hugoniot and isentrope for H_2O are shown for comparison.

The peak H_2O pressure is ∿70 GPa. This is below the 135 GPa limiting pressure possible with infinitely thick tungsten impacting tungsten but above the 15 GPa maximum obtainable via a single shock with the same impact velocity. This result indicates that the method illustrated by Fig. 2 is generally feasible for producing isentropic compression in planar geometries. In order to examine a simpler configuration the flow in a 8-layer experiment utilizing a Lexan, Al, Fe and W projectile impacting also a water Al, Fe, and W assembly was calculated. The entropy generated in the water sample, Δs, from standard conditions in going to an arbitrary state (P_i, V_i, E_i) may be expressed in terms of the temperatures in state i and on the isentrope at the same volume. This is

$$\Delta s = \int_{T_s}^{T_i} \frac{C_v dT}{T} \quad . \tag{1}$$

The specific internal energy difference between these same states is

$$\Delta E = E_i - E_s = \int_{T_s}^{T_i} C_v dT. \tag{2}$$

Assuming C_v = constant, then the above integrals yield

$$\Delta s = C_v \ln(T_i/T_s) = C_v \ln\left(\frac{\Delta E}{3RT_s} + 1\right). \tag{3}$$

Since ΔE is obtainable from the finite difference calculations and the state, E_i, the theoretical isentrope may be calculated, T_s is calculated from Mie-Grüneisen theory, and thus, Δs evaluated.

Figure 4 shows the entropies calculated in this manner for the two symmetrical impact configurations and illustrates the result that the entropy production is small and relatively constant up to very high pressures. Additionally, this entropy production is apparently not strongly influenced by the number of stacked plates.

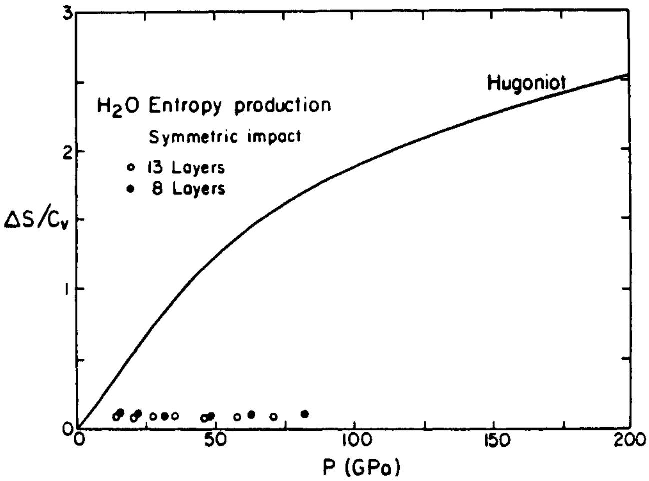

Fig. 4. Specific entropy rise calculated from results of symmetric impact calculations.

CONCLUSIONS

We conclude that nearly isentropic compression may be achieved in one-dimensional flow and the density and pressure may be measured by techniques described elsewhere in this volume[8]. The entropy which is generated is largely the result of the first shock traversing the investigated layer. In the present symmetric impact configuration the first shock in the H_2O layer is caused by the impacting lexan layer and has an amplitude of ∿5 GPa. Interestingly, the observed entropy production is very nearly the Hugoniot entropy at just this first shock pressure of 5 GPa. Evidently, the bulk of the entropy contribution comes from the initial shock, with essentially negligible contribution from succeeding disturbances which elevate the sample to the final isentropic pressure.

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