ONE-DIMENSIONAL ISENTROPIC COMPRESSION

Gregory A. Lysenga* and Thomas J. Ahrens
Seismological Laboratory, California Institute of Technology
Pasadena, California 91125

ABSTRACT

The generation of nearly isentropic pressure-density states in a molecular fluid sample, e.g., H₂O, 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 H₂O impacted at 2.5 km/sec, three-fold nearly isentropic compression to a pressure of 70 GPa is achieved in 10 usec 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 H₂O, CO₂, H₂ and NH₃ 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. In 1972 Kompaneets et al. 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 using an initial variable density sample. The phenomena of a shock wave gradually transforming to a dispersed isentropic compression wave, predicted was verified to a limited extent. However, because of the greater complexity of

*Present address: Jet Propulsion Laboratory, Pasadena, California

0004-243X/82/780231-05 $1.00 Copyright 1982 American Institute of Physics

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 H₂O.

When H₂O is impacted by a composite flyer of Fig. 2 a relatively smooth build-up of pressure in the central H₂O layer results.

![Image of pressure-density relations for water.](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 GPa².)

![Image of layered impact configuration.](Fig. 2. Symmetric impact configuration for nearly isentropic compression of water.)
### Table 1: Assumed Hugoniot Parameters for Impact Calculations(a)

<table>
<thead>
<tr>
<th>Material</th>
<th>( \rho_0 ) (g/cm³)</th>
<th>( C_0 ) (km/s)</th>
<th>( \beta )</th>
<th>( \gamma_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>19.30</td>
<td>4.005</td>
<td>1.268</td>
<td>1.20</td>
</tr>
<tr>
<td>Ta</td>
<td>16.66</td>
<td>3.423</td>
<td>1.214</td>
<td>1.69</td>
</tr>
<tr>
<td>Fe</td>
<td>7.86</td>
<td>3.768</td>
<td>1.655</td>
<td>1.30</td>
</tr>
<tr>
<td>Al</td>
<td>2.70</td>
<td>5.355</td>
<td>1.345</td>
<td>2.13</td>
</tr>
<tr>
<td>Mg</td>
<td>1.78</td>
<td>4.650</td>
<td>1.200</td>
<td>1.46</td>
</tr>
<tr>
<td>Lexan</td>
<td>1.196</td>
<td>2.796</td>
<td>1.258</td>
<td>2.00</td>
</tr>
<tr>
<td>H₂O</td>
<td>1.00</td>
<td>3.111</td>
<td>1.160</td>
<td>2.00</td>
</tr>
</tbody>
</table>

(a) data source, Reference 6

Figure 3 shows the pressure in a particular H₂O 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 H₂O obtained from the assumed equation-of-state properties (Table 1). The H₂O pressure rises monotonically for about 10 usec 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.

The peak H₂O 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, ds, from standard conditions in going to an arbitrary state (T_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

\[ \Delta s = \int_{T_1}^{T_2} C_v \frac{dT}{T} \]  

(1)

The specific internal energy difference between these same states is

\[ \Delta E = E_2 - E_1 = \int_{V_1}^{V_2} C_v \frac{dV}{V} \]  

(2)

Assuming \( C_v \) constant, then the above integrals yield

\[ \Delta s = C_v \ln \left( \frac{T_2}{T_1} \right) = C_v \ln \left( \frac{\Delta E}{\Delta V} + 1 \right) \]  

(3)

Since \( \Delta E \) is obtainable from the finite difference calculations and the state, \( E_i \), the theoretical isentrope may be calculated, \( T_2 \) is calculated from Hugoniot theory, and thus, as 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.

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. 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 H2O layer is caused by the impacting lexan layer and has an amplitude of 15 GPa. Interestingly, the observed entropy production is very nearly the Burgersentropy 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.

Contribution No. 1633, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California. This research was supported under NASA grant NAGW 205.

REFERENCES
7. M. van Thiel, Univ. of Calif. Lawrence Livermore National Laboratory, UCRL 50108 Rev. 1 (1977).
8. N. B. Bedlough and T. J. Ahrens, this proceedings.