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Measurements of Detonation Pressure*

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The "aquarium technique" is applied in the experimental determination of the equation of state for water and Lucite. Results for water are compared with similar results obtained by other methods. Measurements of the peak pressures in the detonation waves are presented for explosives of various types and rates of reaction. The peak pressures were found to be the Chapman-Jouguet or "detonation" pressures of the thermohydrodynamic theory. There was no evidence whatever for the "spike" of the Zeldovich–von Neumann model even though conditions were such that this spike would have been detected by the method employed if it were actually present, at least in the large diameter, nonideal explosives of maximum reaction zone length.

INTRODUCTION

WHEN a shock wave propagates through an undisturbed medium of density ρ_1, all the remaining shock wave parameters may be expressed uniquely in terms of any one chosen parameter if the equation of state is known. For example, pressure, temperature, and particle velocity may each be expressed uniquely in terms of the velocity of the shock wave. The fact that disturbances, even of relatively low pressure, propagate in water as shocks, coupled with the fact that water is transparent, thereby permitting convenient and continuous observation of the shock wave by a streak or framing camera, suggested that water might be used as a "pressure gauge" for measuring transient pressures, including the peak pressures in detonation waves of condensed explosives.

The Rankine-Hugoniot curves for water have been derived by a number of investigators including Kirkwood and Montrall,[1] Kirkwood and Richardson,[2] Richardson, Arons, and Halverson,[3] Arons and Halverson,[4] and Doering and Burkhardt.[5] In these treatments systematic extrapolations of Bridgman's[6,7] PVT data for water were made. Probably the most comprehensive extrapolation of Bridgman's PVT data, however, was carried out by Snay and Rosenbaum[8] who used more recent data of Bridgman[9,10] which for water extended to 36 500 kg/cm² and for ice VII to 50 000 kg/cm².

A different approach was used in a later study by Rice and Walsh.[11] In their method an intense plane shock wave was generated in an aluminum plate by the detonation of a slab of composition B in contact on one side of the plate. The shock through a portion of the plate was then transmitted into water. Higher pressures in the aluminum plate were reported by "slapping" the aluminum plate with a thin, high velocity, explosively driven plate rather than detonating the charge directly in contact with the test plate. By application of a special streak camera technique pioneered by Walsh and co-workers and through use of a previously derived equation of state for aluminum the shock velocity in water was determined as a function of the corresponding shock pressure in the aluminum at the interface. Continuity conditions of pressure and particle velocity across the interface between the aluminum and water were then applied to determine the Hugoniot curves for water.

In determining shock parameters for water a factor which should be considered is the possibility of a phase change of the medium within the shock wave. This possibility was investigated by Snay and Rosenbaum[8] and by Rice and Walsh.[11] According to Snay and Rosenbaum the Rankine-Hugoniot curve for supercooled water and the Rankine-Hugoniot curve for partially frozen water are never far apart, and thus the shock velocity would not be materially affected if freezing did occur. Since partial freezing of a liquid should lead to reduce transparency because of differences in indices of refraction of water and ice, Rice and Walsh carried out some transparency experiments of water being traversed by a shock wave in the pressure range of 30 to 100 kbars. No sign of opacity due to freezing was observed. They concluded therefore that even though p, T conditions might be proper for freezing under static conditions, the time the liquid was under the correct conditions within the shock was apparently too short for freezing to occur.

In using water as a pressure gauge (by observing the transmission of the shock into it) one must calculate from the measured shock pressure in water the pressure in the adjacent medium of interest from which the

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water shock is transmitted. In the initial application by Holton[12] of the "aquarium technique" for the measurement of pressure, two procedures were used to perform this calculation. The first method, which was considered the more exact one, was patterned after a treatment given by Riemann for a shock propagating across a boundary into a medium of lower impedance. The second method utilized the shock "impedance mismatch" equation

$$p_i = p_t(\rho_t V_t + \rho_i V_i)/2\rho_t V_t, \tag{1}$$

where p is pressure, ρ is initial density of the medium before being traversed by a shock, V is the velocity of the shock, and subscripts i and t designate the incident medium and the transmitting medium, respectively. Although the impedance mismatch equation was expected on theoretical grounds to be accurate only when the wave reflected at the interface is a weak shock, in the investigations of Holton, where the reflected wave was a rarefaction, Eq. (1) was found to yield results in very good agreement with the first method. Therefore, the method appears reliable whether the reflected wave is a release or a shock wave.

A third more direct method was used in this investigation in which the equations of state for water and Lucite were obtained by direct simultaneous observation of the shock velocity and the free surface velocity. This method while developed in this investigation was referred to and summarized by Cook, Pack, and McEwan.[13] Therefore, only essential points not outlined there are presented in this article. The application of the aquarium technique in the measurement of detonation pressures for various ideal and nonideal explosives is then presented and results discussed.

EXPERIMENTAL

(a) Shock Parameter Determinations

The shock parameters which are of interest in this study are related by the familiar hydrodynamic equations

$$p - p_i = \rho_i V W \doteq p \tag{2a}$$

$$W/V = (1 - \rho_i/\rho) \tag{2b}$$

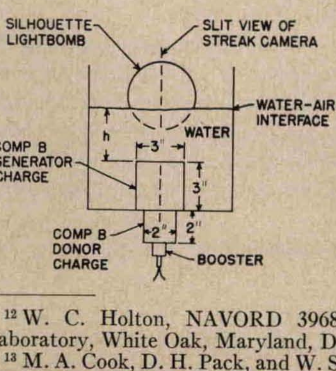

FIG. 1. Aquarium setup for measuring velocity of water shock along the charge axis and free surface velocity.

and the approximate relation

$$W \doteq V_{fs}/2, \tag{3}$$

where V_{fs} is the free surface velocity, and W is the particle velocity, the subscript i indicating initial conditions in the undisturbed medium. Equation (3) expresses the basic, now well-established, postulate of the Goranson theory that free surface velocity is approximately twice the particle velocity in the shock in the medium immediately beneath the free surface.

The method used for determining the shock-parameter data for water and some of the data for Lucite consisted of simultaneous measurements of the shock velocity immediately inside the free surface and the free surface velocity as the shock emerged from the water or Lucite. Observations of the shock and free surface velocities were made with a rotating mirror

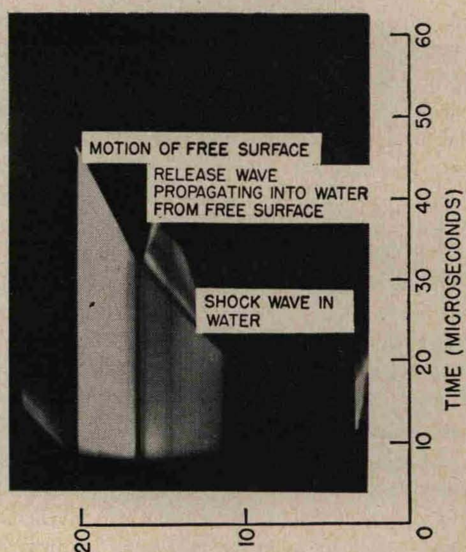

FIG. 2. Typical streak camera trace obtained using the arrangement of Fig. 1 (shock parameter determination for water).

streak camera using diffuse backlighting from an explosive flash bomb. This method is illustrated in Fig. 1. Because point-initiated charges were used it was necessary that the slit view of the streak camera lie along the charge axis in order to obtain the correct values of shock velocity and the corresponding free surface velocity. Care was taken also to ensure that the free surface was coincident with the optic axis of the system, i.e., that the view of the camera was flush with the free surface.

Two sizes of aquaria were used, namely 6×6×6 in. and 12×12×8 in., the size being dictated by the height h of water above the receptor charge. As h was increased above a certain limit, the dimensions of the aquarium had to be increased because generally shattering of the glass propagates at higher velocity than the shock in the liquid.

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