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Limitations of the Reflected-Shock Technique for Studying Fast Chemical Reactions

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USE of the region behind a reflected shock wave for chemical kinetic studies presupposes that the temperature is known. Three easily measured properties are available from which the temperature can be calculated with one-dimensional theory: incident Mach number M_s, reflected Mach number M_{rs} (defined in each case as wave velocity divided by sound speed at initial conditions), or reflected shock pressure p_5. Two previous articles have dealt with the validity of such calculations for the case of argon. Strehlow and Cohen[1] used measured M_{rs} to compute temperatures 300–500°K lower than those computed from measured M_s. Skinner[2] measured p_5 and found it to give temperatures only 30–50°K lower than those calculated from M_s. It was believed that further information bearing on this point might be derived from simultaneous measurements of all three properties, also in argon.

The shock tube used is made of $2\frac{1}{2}$-in. i.d. stainless-steel tubing, with a 15-ft expansion section and a $5\frac{1}{2}$-ft driver. Incident and reflected shock velocities were measured with two Berkley time-interval meters adjusted to different trigger sensitivities and operated by miniature piezoelectric pressure transducers.[3] Pressures were measured with a SLM[4] transducer placed 6 in. from the end plate. This pickup, which has the property of static response, was calibrated by means of a dead-weight gauge. The p_5 measurements were taken from photographs of oscilloscope traces and, owing to finite line widths and a slight ringing of the pickup, they contain an uncertainty of about 2%.

Both incident and reflected shock velocities were measured over two regions in the shock tube, in separate experiments. The near region had two probes located 6 and 10 in. from the end plate, while the far region had the probes 6 and 25 in. from the end plate. The greatest uncertainty existed in measurements taken of the velocity of the fast-moving incident shock as it traversed the 4 in. of the near position; it was about 1%.

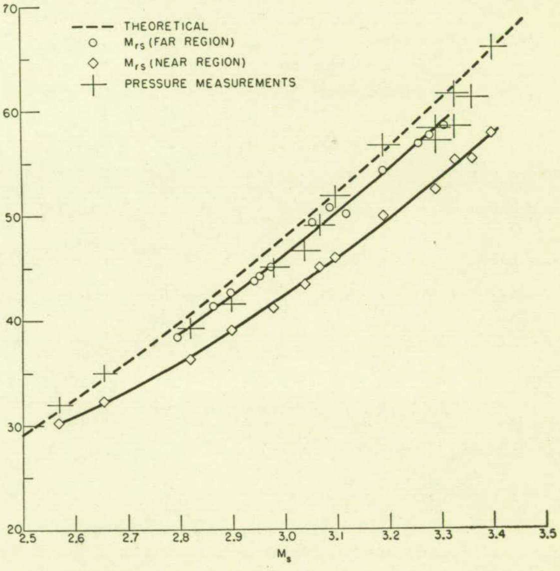

FIG. 1. P_{51} values for argon calculated from M_s, M_{rs} (near region), M_{rs} (far region) and pressure measurements.

Figure 1 shows all the data plotted in terms of M_s against the ratio P_{51}(p_5/p_1, where the initial pressure p_1 was 150 mm Hg in all cases). The dashed curve is simply the ideal one-dimensional relation between P_{51} and M_s. The other two curves show P_{51} computed from measured M_{rs} against simultaneously measured M_s for the near and far regions. If the reflection were ideal, all three curves would coincide. However, that the curve for the far region lies closer to theory than that for the near region, and that both lie below the ideal, could be explained by a deceleration near the back wall, followed by the measured acceleration. Such a phenomenon is predicted by Mark[5] for argon between $M_s = 1.4$ and 2.8. Since most of the data are not in this Mach number region, the shock speed variations herein encountered must be a result of another phenomenon.

The measured values of P_{51} are denoted by crosses in Fig. 1; these are pressures corresponding to the vertical rise of the oscilloscope trace when the reflected shock passes the pickup. It can be seen that these measured P_{51}'s fall essentially on the curve for reflected shock pressures calculated from the far position velocities, even though the pressure pickup was at the near position. This concord between the pressure measured at the 6-in. position and the far-position reflected-shock speed indicates that the wave, as it passed the SLM pickup, was traveling at a speed near this average value. This would mean that the pressure, as well as the shock speed, depends upon the location selected to make the measurement. The departures of measured P_{51}'s from the ideal, when translated to temperature, were averaged for M_s ranges 2.5–3.0 and 3.0–3.5 and amounted to about 40° and 60°K respectively, just as Skinner concluded.

Following the initial pressure jump, the traces show a continued slow rise, such as Skinner described. At 500 μsec after the jump, many of the traces indicated a pressure slightly larger than that expected for an ideal reflection.

In conclusion, it appears that the values of both M_{rs} and p_5 depend upon the position selected to record the measurement. It is believed that reaction temperatures derived from pressure measurements are better than those from M_{rs} measurements, because the pressure reflects the time-temperature history over the region in question.

[1] R. A. Strehlow and A. Cohen, J. Chem. Phys. **30**, 257 (1959).

[2] G. B. Skinner, J. Chem. Phys. **31**, 268 (1959).

[3] Made by us, using Clevite Corporation's PZT–5 crystal elements.

[4] Purchased from Kistler Instrument Company, Model No. 680.

[5] Herman Mark, "The interaction of a reflected shock wave with the boundary layer in a shock tube," NACA TM 1418 (1958).