Assessment of Low-Efficiency Driver Gases in Shock-Tube Flows over a Wide Range of Conditions: Cost Analysis and Optimal Shock-Tube Design

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Abstract

With a high sound speed, helium is an optimal driver gas in shock-tube experiments. However, the increasing consumption from industries, such as medicine and defense, tripled the unit cost of helium in the last two decades, raising an economic concern for shock-tube experiments. Alternative driver gases, such as hydrogen, nitrogen, and methane, increase cost effectiveness for the experiments, but remain underexplored in the context of chemical-kinetics experiments behind reflected shock waves. This study characterizes the performance of alternative driver gases over a wide range of conditions in a high-pressure shock tube with a divergent nozzle. A departure term is introduced to describe the difference between the real and ideal driver-to-driven pressure ratios ($p4/p1$), which is a strong function of the driver-to-driven sound speed ratios (a_4/a_1) and the incident-shock Mach number (M_s). An empirical model of the departure term was developed from experiments over reflected-shock temperatures of 445 – 5768 K and reflected-shock pressures of 0.23 – 4.78 atm. Predicted a_4/a_1 values agree well with the measured data over M_s of 1.35 – 5.07. The results indicate that hydrogen is the most efficient in producing shock waves with higher Mach numbers for the same $p4/p1$, followed by helium, methane, and nitrogen. This difference in Mach number is more evident at higher pressure ratios. The departure term increases with incident Mach number non-linearly for all driver gases; however, driver gases with lower efficiencies have higher departure values. The results herein will provide insight into achieving the required initial conditions to reach desired reflected-shock conditions, optimizing shock-tube design, and reducing the cost of future shock-tube experiments.