# SHOCK TUBE EVALUATION OF HYDRAULIC FLUIDS

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## INTRODUCTION

While the shock tube has been used extensively in the study of gas-phase reactions, relatively few studies have been made of gas-liquid reactions. The main reason for this has been the difficulty in interpreting the data obtained when two phases are initially present, because the additional steps of drop break-up, evaporation and mixing need to be considered, as well as chemical kinetics.

A study of the combustion process when n-hexadecane is injected as a fine spray into shock-heated air was made by Mullaney (Ref. 1). By high-speed photography he was able to observe injection of the spray, evaporation of the droplets, and spontaneous ignition. In most of his experiments combustion started before evaporation was complete. Shock tubes have also been used by Morrell and co-workers (Ref. 2,3) and by Hanson, Domich and Adams (Ref. 4) to study the break-up of liquid jets by rapidly moving gas streams. These investigators used inert liquids to study atomization of the liquids without the complications introduced by combustion, and were able to obtain equations relating atomization time to physical properties of the liquid and gas.

The original intent of this work was to develop a method of rating the ignition characteristics of fire-resistant hydraulic fluids that could be related to the single-cylinder engine test (Ref. 5) currently used, yet require much less fluid for an evaluation. The results shed some light on the parameters governing liquid-gas reactions.

## EXPERIMENTAL

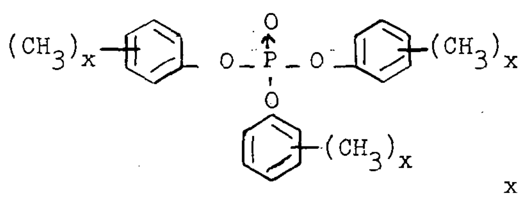
The shock tube used for these experiments has been described in detail elsewhere (Ref. 6). Briefly, it is 3 inches in diameter, with 12-foot low-pressure and 20-foot high-pressure sections. Shock speeds are measured by timing the passage of a shock wave between stations 55 and 7 inches from the closed end of the low-pressure section. Gas temperatures and flow velocities are calculated from the shock speeds. A piezoelectric pressure transducer is mounted in the top of the tube, 3 inches from the closed end, while a fused quartz window (covered except for a 2 mm vertical slit) is in the side of the tube, also 3 inches from the end. Light emitted by combustion in the tube is detected by a photo-multiplier tube 8 inches away from the tube, which also was covered except for a 2-mm vertical slit. Because of the slits, light emitted only from gas 3 inches from the end of the tube was detected.

A 0.01 ml drop of the liquid to be tested was placed on an 18 gauge copper wire placed crosswise in the tube just below the quartz window. Since the wire curved downward slightly in the middle, the liquid remained together as a hanging drop, only a small fraction being in close contact with the wire. In all cases, the driver gas was helium at 85 psia, while the initial air pressure in the low-pressure section was variable.

## RESULTS

The ignition time of a fluid sample is taken as that between the passage of the reflected shock past the pressure transducer and the moment when the light intensity reaches 10% of its maximum value. These ignition times have been plotted against the calculated temperature of the air behind the reflected shock wave. While the incident shock wave is important in causing break-up of the fluid droplet, the fluid droplets remain in the incident shock region for only about 0.3 millisecond compared to total ignition times of 1 to 5 milliseconds. Therefore the temperature behind the reflected shock wave seemed to be the most meaningful single number by which to characterize the experimental conditions.

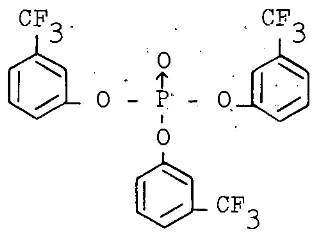
Figure 1 shows the ignition delays found for xylene and three hydraulic fluids. MS-2110-H is essentially a light hydrocarbon lubricating oil, while MIL-H-19457 is a phosphate ester, one of the most fire-resistant fluids available of which the general formula is




x = 0, 1 or 2

Since, in the engine test of Reference 5, the actual measured quantity is the compression ratio required to cause ignition of a spray of hydraulic fluid in 2 milliseconds time as the piston is approaching the top of its stroke, it is appropriate to compare the engine compression ignition rating (expressed as a compression ratio) to the reflected shock temperature required to give ignition of the fluid in 2 milliseconds. Engine compression ignition ratings of the above four fluids have been measured (Ref. 5), and have been plotted against the 2-millisecond shock temperatures in Figure 2. The correlation between the two tests is good, but the linear relationship found over the range covered experimentally cannot be expected to hold for higher or lower ratings.

Of a number of exploratory hydraulic fluids tested one, of formula




had the high ignition temperature of 1365°K., which from the extrapolation of Figure 2 would indicate an engine test rating of about 80.

## DISCUSSION

There is, and probably will be for some time, a question as to the relative importance in the ignition process of the physical factors of drop break-up, evaporation, convective and diffusive mixing on the one hand, and chemical reactivity on the other.

Morrell and Povinelli (Ref. 3) have developed an equation for the time for break-up of liquid cylinders by shock waves, which should also apply approximately to drops. The break-up times of the 0.01 ml drops of "standard" liquids used in the above experiments have been calculated, as follows:

| Liquid | Calculated Break-up Time, milliseconds |
|---|---|
| MS-2110-H | 0.24 |
| Fluid AV | 0.31 |
| Xylene | 0.81 |
| MIL-H-19457 | 0.25 |

These drop break-up times do not correlate with the ignition data, since the break-up times of the most and least flammable liquids are the same, while the calculated break-up times for Fluid AV and xylene, which have similar ignition temperatures, are different. Moreover, the boiling points of these latter two compounds differ considerably, being 325° and 140°C, respectively. It seems, therefore, that under these conditions the physical properties of the fluids are less important than chemical reactivity in controlling the ignition delays.

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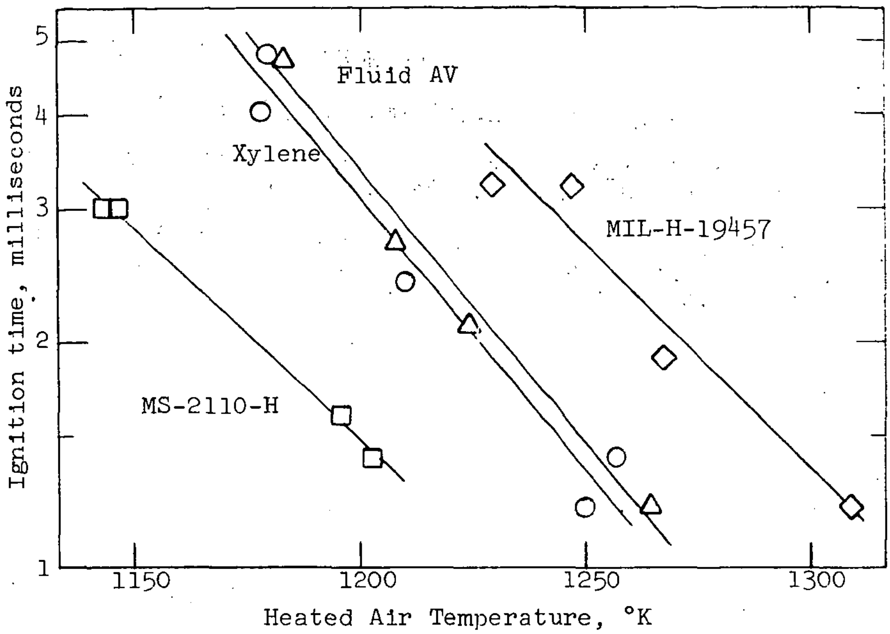


Figure 1. Shock tube ignition of hydraulic fluids

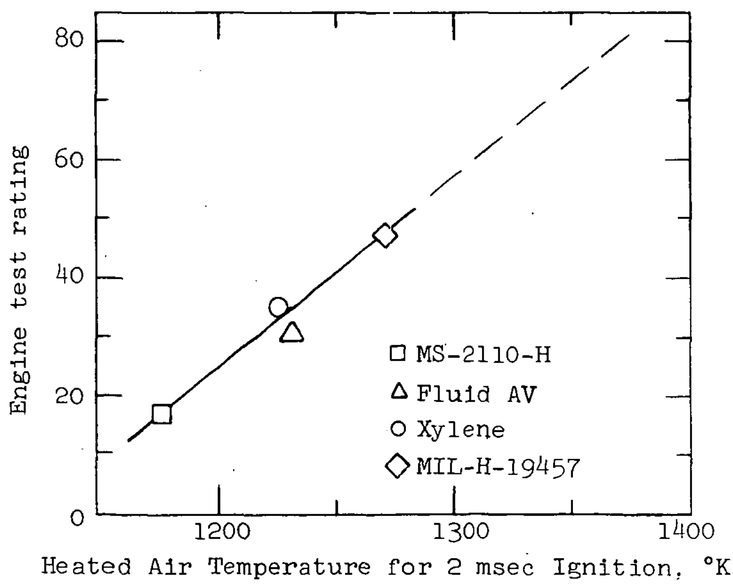


Figure 2. Calibration curve - shock tube versus engine test rating