A Study of Shock Wave - Hexane Droplets Interaction

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Introduction

An interaction between fuel droplets and shock wave is of great importance in several areas of technical activities ranging from explosion protection to application in pulsed detonation engines. Although the process has been studied for many years the understanding is not satisfactory yet. Thus presented research have been carried out to get knowledge about basic features of behavior of big hexane droplets hit by the shock wave propagating in air.

The test stand

The test stand is shown in Figure 1a. The chamber (Fig. 1b) was designed to investigate the process of interactions between the shock wave and droplets. The chamber is mounted at the end of rectangular shock tube. Length of the tube is 5 m. Cross-section is 112x72 mm. The driving section (length 1.5 m) is filled with combustible mixture (17% O_2, 33% H_2, 50% He). The driven section filled with air at atmosphere pressure is separated from driving section by plastic diaphragm. The detonation in driving section breaks the diaphragm and generates shock wave in driven section. The driven section is connected with visualization section (Fig. 1b) equipped with hexane droplets generation system. At the end of tube is a dump tank. Whole test stand is situated on a steel support.

a)

b)

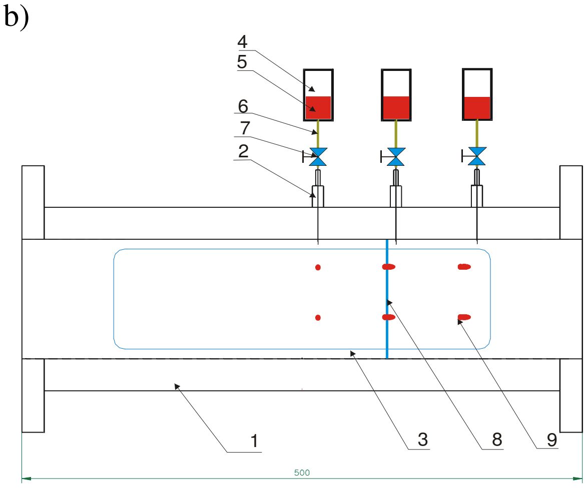


Fig. 1. The experimental test stand: a) picture of the test stand, b) schematic diagram of the visualization section of the shock tube.

Main body (1) of the visualization section is made from duralumin (Fig. 1b). It is equipped with set of needles (2) and high-quality glass windows (3). Because of large area of window the maximum pressure behind shock wave was limited and respectively maximum Mach number of shock was 3.0. Hexane (5) is fed from small tanks (4) and then trough elastic tubes (6) and valve (7) is entered the needle or needles (2). Number of needles can be changed during the experiments, distance between needles is 50 mm. In first research only one needle was mounted, in next series of experiments three needles were used. Diameter of droplets depends on diameter of the needles. Rate of droplets falling depends on hydrostatic pressure of liquid and valve (7) opening. These parameters are controlled by changing size of replaceable needles, setting the valves (7) and position (height) of hexane containers (4). By choosing appropriate parameters the different number of droplets (9) is generated in the observation chamber filled with air. The shock wave (8) passing along the tube causes disturbing of droplets (9) what is recorded by high speed camera with a Schlieren system. The camera is synchronized with igniter which is connected with spark plug mounted in the driven section. The test stand is also equipped with pressure measurement system which consists of two sensors and amplifiers and oscilloscope. The sensors are placed in front of windows and can be used to measure shock velocity and pressure profile.

Results

The experiments were carried out for two different Mach numbers of the shock wave: 2 and 2.9. Also the diameters of droplets were changed by means of use of different needles. The needles internal diameter were 0.3 mm, 0.5 mm, 0.7 mm and 1.0 mm. Diameter of droplets was about 0.6 mm, 1.0 mm, 1.3 mm and 2.0 mm respectively. Recording of image of the process of interaction between shock and droplet was the main goal of the experiments. Apart from that the pressure measurement was used to calculate the speed of the shock and pressure behind shock front.

Figure 2 shows the typical image of the interaction and definition of dimensions used in further analysis. The observation of over one hundred experiments showed that there was no significant qualitative difference between behavior of droplets of different sizes. The only difference between them is that bigger droplets move slower and need more time for dispersion. General tendency is that stronger shock (M=2.9) generates bow shock in front of droplets what accelerates the heating, dispersion and evaporating of droplets in respect to slower shock (M=2). An analysis of motion of the droplets is shown on following graphs (Fig. 3 and 4).

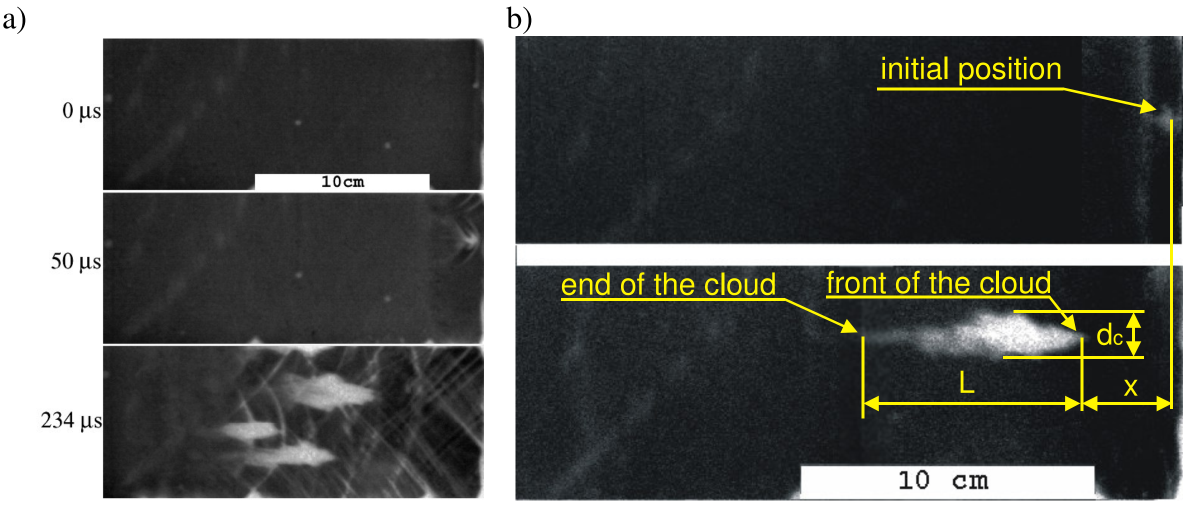
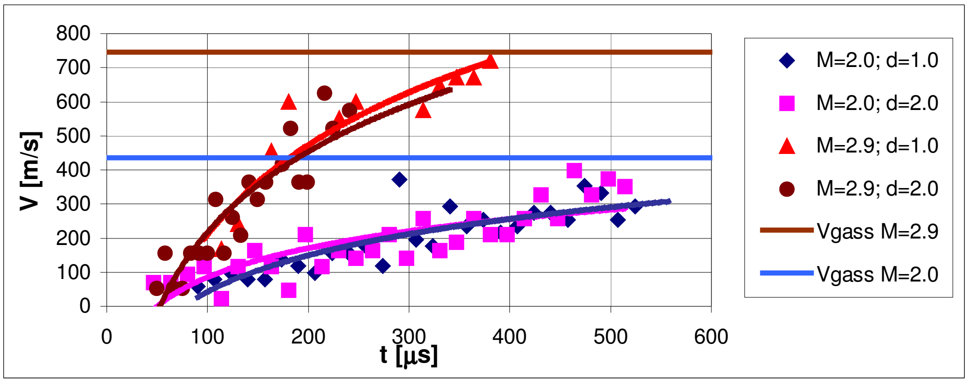


Fig. 2. Images of the process: a) interaction of three droplets (d=2 mm) with shock wave (M=2.9), b) dimensions of the mist cloud: x-shift, d_c-diameter, L-length.

a)



b)

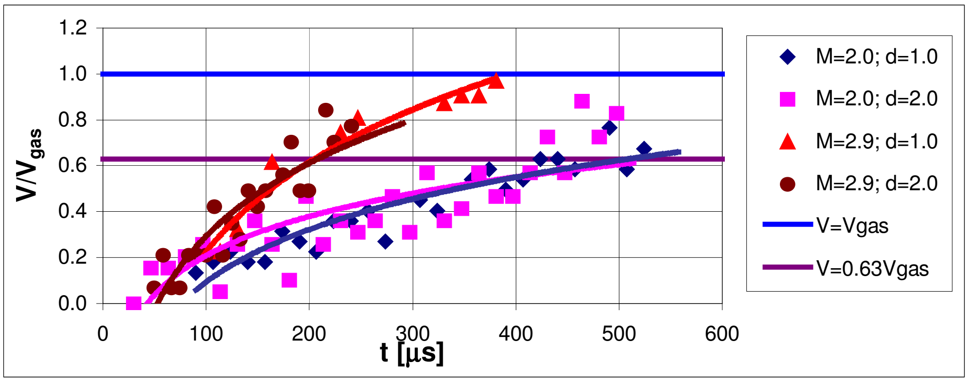


Fig. 3. a) Velocity of droplets for different conditions and b) response time estimating.

First graph shows accelerations of droplets for different conditions. Second graph shows response time. The response time is defined as the time when the velocity of droplet is equal to 0.63 of velocity of the gas behind shock wave. Measured time is shorter than Stokes time (Eq. 1). It means that droplets are broken before they achieve mechanical equilibrium with surrounding gas. The Weber numbers (Eq. 2) are very high, We>>O(1) thus the droplets are easily broken by the wave. Low Ohnesorge number (Eq. 3) On<0.1 means that internal viscous forces in droplet are small in comparison to surface tension forces and do not play role in dispersion process. In such condition shear breakup mechanism of dispersion is dominating.

$$\tau_p = \frac{\rho_d d_d^{\ 2}}{18\mu_{air}} \quad \textbf{Eq. 1} \qquad We = \frac{\rho_{air} V_{air}^2 d_d}{\sigma_d} \quad \textbf{Eq. 2} \qquad On = \frac{\mu_d}{\sqrt{\rho_d d_d \sigma_d}} \quad \textbf{Eq. 3}$$

Also changes of shape of the droplets were analyzed. As an example the relation between cloud diameter and Weber number is shown (Fig. 4). There is a good correlation of these two parameters for various droplet diameters and velocities of the shock waves.

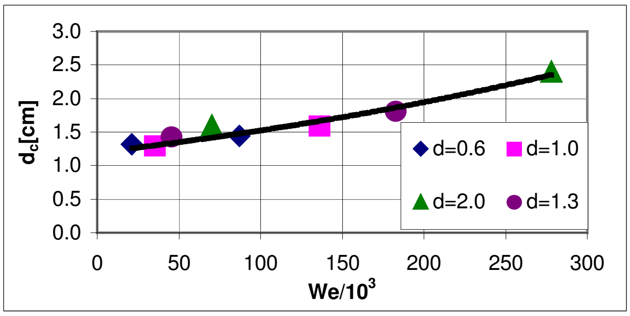


Fig. 4. Diameter of cloud after 200 μs as a function of Weber number.

Conclusions

Obtained results of experiments show main features of the interactions between droplets and shock wave. The nature of the process is similar for various droplet sizes and Mach number of the shocks. The differences have mostly quantitative character.

Droplet hit by the shock is accelerated, break into mist cloud and vaporized. Approximate time of breaking of droplet is about 100÷300 μs. Approximate time of the complete dispersing and acceleration of the fuel droplet varies from 300 to over 500 μs and depends both on diameter of droplet and speed of the shock. The diameter of cloud during dispersion is controlled by Weber number although the dispersion time is strongly related to diameter of droplet and less to Mach number of shock.

It was observed that acceleration of the droplet is more related to shock speed than droplet size. The most significant difference between slower and faster shock depends on creating bow shock in front of the droplet what cause faster vaporization and dispersing.

The concentration of droplets in presented research is relatively small. Therefore there were not observed any noticeable interactions between droplets themselves and droplets and the shock. Images made for three droplets show exactly the same behavior (movement, dispersion) like in single droplet case. The only difference is observed in last period of the process, one bigger cloud of mist is created by joining smaller ones. It is formed from several mist cloud generated by separated droplets. Also the shape of the front of shock is not disturbed by the droplets.

The experiments allowed recognizing the basic features of the interaction of shock wave with fuel droplet. It also gives knowledge about parameters of the dispersed droplets: diameter, dispersion time, velocities. The next step of research could be detailed numerical simulation of the process.

References

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