

Shock Attenuation Using Water Mists

K. Kailasanath and D. Schwer

Naval Research Laboratory, Code 6410

Washington, DC 20375

E-Mail: kailas@lcp.nrl.navy.mil

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Introduction:

Recent events have visually demonstrated the extensive damage that can be inflicted on personnel and facilities by the detonation of commonly available explosives. There is a critical need to develop and demonstrate anticipatory damage control response systems that will limit damage from explosions. Ideally, such a system should have a dual utility, function as a fire suppression system for peacetime fires and as a blast mitigation system in combat or terrorist scenarios. A water-based system has the potential to fulfill this dual need and at the same time reduce life-cycle costs.

The history, benefits and implementation of a water-mist fire suppression system for compartment fires has been discussed elsewhere [1]. A survey of the use of water (bulk, sprays, mists etc.) as an agent for blast mitigation has also been conducted [2]. That survey showed that there are several ways in which the use of water sprays can mitigate the effects of an explosion. It may 1) break up larger droplets into finer mist, 2) directly lead to an attenuation of the shock waves produced, 3) reduce the intensity of secondary shock and pressure waves, 4) slow down or quench the chemical reactions taking place behind the shock waves, and 5) dilute the concentration of explosive gases in the enclosure and hence prevent a secondary gas explosion or fire. In addition, the interaction depends on whether we are dealing with a shock wave,

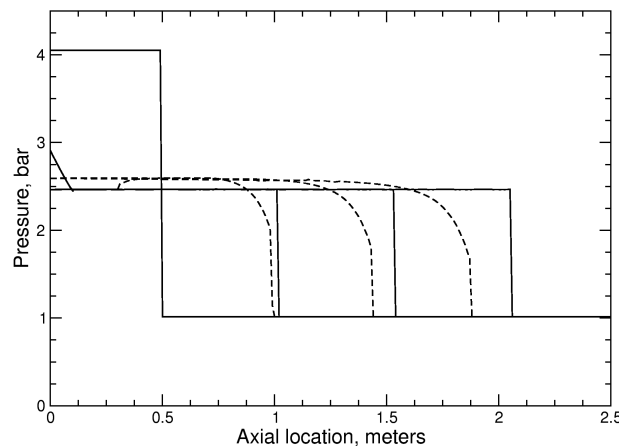
detonation or deflagration wave. Under certain circumstances, the introduction of water spray could have an adverse effect by improving fuel-air mixing and accelerating flame propagation. The overall conditions under which water sprays may be effective for explosion mitigation has been addressed by Thomas [3]. The focus of this paper is on one aspect of the overall problem: shock attenuation using water mists. After a brief review of previous shock-tube studies, results from numerical simulations of the attenuation of shock waves is presented.

Previous Shock-Tube Studies:

There have been a number of experimental and numerical studies dealing with shock wave attenuation in a multiphase environment [e.g., 4-6]. Like the classical paper by Sommerfeld [4], these studies typically focus on attenuation using solid particles such as glass beads rather than liquid droplets like water mist. From such studies, a general attenuation law that can be used to calculate the instantaneous Mach number of a shock wave traveling through a cloud of particles has been formulated [5]. The work of Chang and Kailasanath [6] does consider liquid droplets in addition to solid particles but the droplets simulated were fuel droplets that added energy to the flow due to combustion. A key observation from that study was that for a specified mass loading, the shock velocity is reduced in an exponentially decaying manner to the same equilibrium velocity regardless of the size of the particle or droplet. However, increased attenuation rates were observed to correspond to smaller particle sizes. When droplet breakup and vaporization effects were included, the attenuation rate increased further but the same equilibrium velocity was attained. Although the shock wave velocity was reduced considerably, a small increase in the maximum pressure behind the shock wave was also noticed. In the current work, this phenomenon is investigated more closely and the effects of additional factors such as the driver section size and shock Mach number are also considered. The focus of our work has also shifted to attenuation using fine water mists ranging in size from 5 to 50 μm .

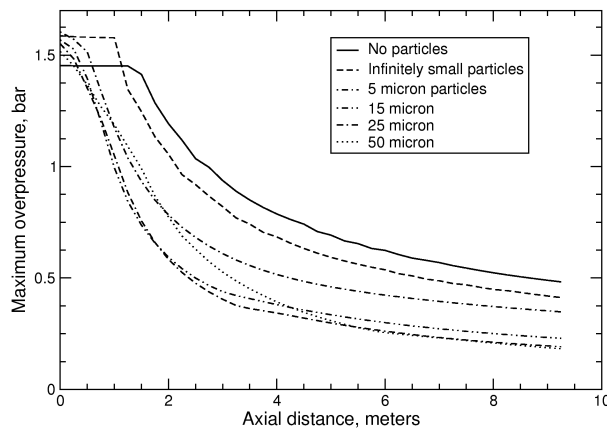
Current Shock-Tube Studies:

Typical pressure profiles at a sequence of times from two simulations are shown in the figure below. One is a base case without any droplets (solid lines) and shows a steadily



propagating shock wave with the characteristic “plateau” in the pressure behind the wave front. The shock position at the corresponding times for the case with water droplets (dashed lines) clearly shows the propagation rate of the shock wave is reducing significantly with time. The pressure just behind the wave front

is also lower. However, the peak overpressure is higher than the “plateau” pressure observed in the case without any water droplets. If the overall goal is to mitigate all the “ill” effects of the shock wave, lack of reduction of the peak overpressure is certainly a matter of concern.



Many realistic explosion scenarios involve shock waves that decay from the center of the explosion rather than the steady shock waves typical of shock tubes. A decaying shock wave can be simulated in a shock tube by decreasing the size of the driver section. In these cases, the expansion

waves after reflection from the confining wall erode the “plateau” pressure behind the shock wave leading to a decaying shock wave. In all simulations with a decaying shock wave, there is a reduction in the maximum overpressure as shown in the above figure. Overall mitigation beyond the reduction due to the natural decay of the shock wave is observed with particles of all sizes.

Summary:

The ability of water mists to reduce the propagation rate of shock waves is unquestionable based on the evidence available. In general, finer droplets do increase the attenuation rate. The reduction in propagation rate does not necessarily lead to a reduction in the peak overpressure because the peak overpressure is generally observed to occur at some distance behind the shock front. This result is clear from shock-tube simulations with a large driver section. However, shock tube simulations with a short driver section are more representative of practical explosions. In such simulations, the expansion waves after reflection from the confining wall erode the pressure behind the shock wave leading to a decaying shock wave. In such instances, the small increase in overpressure due to particle loading is overshadowed by the decay of the shock wave. Even in these cases, there is further attenuation of the shock velocity due to droplets. These results highlight the need to consider geometries and physical conditions representative of specific explosion scenarios in assessing the overall effectiveness of water mist and other mitigating agents.

References

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