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SHORT COMMUNICATION

Numerical Simulation on Dispersal Character of Fuel by Central HE

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ABSTRACT

A fuel-air explosive (FAE) device consists of a shell (top-end cover, bottom-end cover, shell-side wall), a mixed fuel, a central pipe and a burst high-explosive (HE) charged in the central pipe. The mixed fuel is filled in a column structure and dispersed by the explosion drive of central burst HE in the central pipe. The dispersed fuel mixes with air, which produces combustible cloud which can be detonated. That is the fuel-air explosive (FAE). The height and ignition position of the central HE charged column affect the fuel dispersal process. The initial stage of fuel dispersal was simulated by numerical computation. The simulation result indicated that the distribution of fuel dispersal velocity, when the central HE is ignited at the end, is not the same as that when the central HE is ignited on the axis of the central HE simultaneously. When the ratio of the column height of the central HE and that of the FAE device is 0.64~0.73, the distribution of fuel dispersal velocity has little difference when the central HE is ignited at the end of column. But, when the ratio of the column height of the central HE and that of the FAE device is 0.89, the fuel axial dispersal velocity is obviously more than that when the ratio of the column height of the central HE and that of the FAE device is 0.64~0.73.

Keywords: Fuel-air explosive, explosion, numeral compute, dispersal velocity, FAE

1. INTRODUCTION

The explosion shock wave strength of the fuel-air explosive (FAE) depends on the combustible cloud concentration, and the cloud is created by the explosion drive of a central high-explosive (HE). The fuel is dispersed under the explosion load of the central HE and mixes with air. The fuel cloud is initiated by the second ignite device again. The FAE device is generally a column structure. The fuel-cloud concentration formed by the fuel dispersal is a function of time and space, and is a key technology[1-3.] The fuel dispersion process can be divided into a few stages[4-9].

It is difficult to analyse and simulate the whole dispersal process. Especially, the variety regulation of cloud concentration with time and space could not be determined yet. Under the action of central HE explosion, the shell of FAE device deforms and breaksup, then the fuel in the device starts to disperse forward. The distance of fuel dispersal is related to the initial dispersal velocity. In some cases, the bigger the initial dispersal velocity, the more far will the fuel go. Therefore, the research on the initial dispersion velocity of fuel is important. If the central HE charge is too much, its explosive product makes the fuel cloud ignited during the fuel dispersal, which produces a so-called disorder conflagration phenomenon. Whereas, when the central HE charge is too small, the fuel cannot obtain the enough energy to dispersal. Therefore, the influence of the central HE mass on the dispersion process

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of the fuel is of great value to develop a new FAE technique. For a given central HE mass, the changing sizes of the central HE and ignition method is a primary way to control the cloud concentration.

The quantitative relationships between the dispersal velocity and the central HE column sizes for the three ignition methods of the central HE have been found. The influence of the central HE charged size and ignition method on the dispersal process of fuel was studied by the numeral compute. The fuel dispersal velocity is considered only.

2. ASSUMPTIONS

After the central burst HE detonated, the stress wave is created in the fuel and the explosion product gas of HE expands. Under the action of stress wave and explosion product gas, the FAE device shell breaks up and the fuel moves forward. The explosion pressure load is considered only and the explosion temperature effects of the central HE is ignored.

An FAE device is generally a column structure, shown in Fig.1. In this study, the device height is supposed as 0.734 m and dia as 0.4 m. The top cover thickness of the device is supposed as 7 mm, the bottom cover thickness as 7 mm, and that of the shell wall as 3 mm. The density of shell material for FAE device is ρ = 7830kg/m^3, the shearing module is G = 7700 MPa, and the yield stress is [σ]=900 MPa. The central high explosive is TNT, whose density is 1.64×10^3 kg/m^3, and the mass of HE is 1.165 kg. Let the ratio of the height of the central HE and that of FAE device be h/H, which were taken as 64 per cent, 73 per cent, and 89 per cent, respectively, in the numeral computation. According to the height percentages and the given central HE charge mass, the diameter of HE charged column can be obtained.

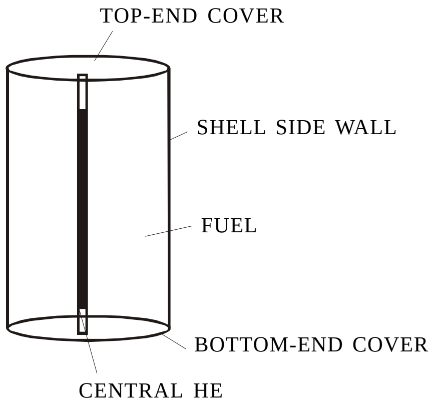


Figure 1. Centre axis of the FAE device sketch.

3. MATHEMATICAL TREATMENT

The dynamic analytical software ANSYS/LS-DYNA was used in the numerical simulation. The momentum equation is:

$$\sigma_{ij,j} + \rho f_i = \rho \ddot{x}_i \tag{1}$$

where $\sigma_{ij,j}$ is the Cauchy stress, f_i is the unit mass volume force; and $\ddot{x}_i$ is the acceleration.

The conversation equation of mass is:

$$\rho = j\rho_0 \tag{2}$$

where ρ is density, ρ_0 is the initial density, $J = \left|\frac{\partial x_i}{\partial X_j}\right|$, x_i is the space coordinate and x_j is the matter coordinate, and $\frac{\partial x_i}{\partial X_j}$ is the strain grads.

The energy equation is:

$$\dot{E} = VS_{ij}\dot{\varepsilon}_{ij} - (p+q)\dot{V} \tag{3}$$

where V is the volume, $\dot{\varepsilon}_{ij}$ is the strain rate tensor, q is the artificial viscidity, and δ_{ij} is the Kronecher symbol.

$$q = \begin{cases} ?l\left|\dot{e}_{kk}\right|(Q_1 l\left|\dot{e}_{kk}\right| + Q_2 c & \left|\dot{e}_{kk}\right| < 0 \\ 0 & \left|\dot{e}_{kk}\right| < 0 \end{cases}$$

where l is the cubic root of an element volume, c is the sound velocity in material, and Q_1=1.5, Q_2=0.06^{10}.

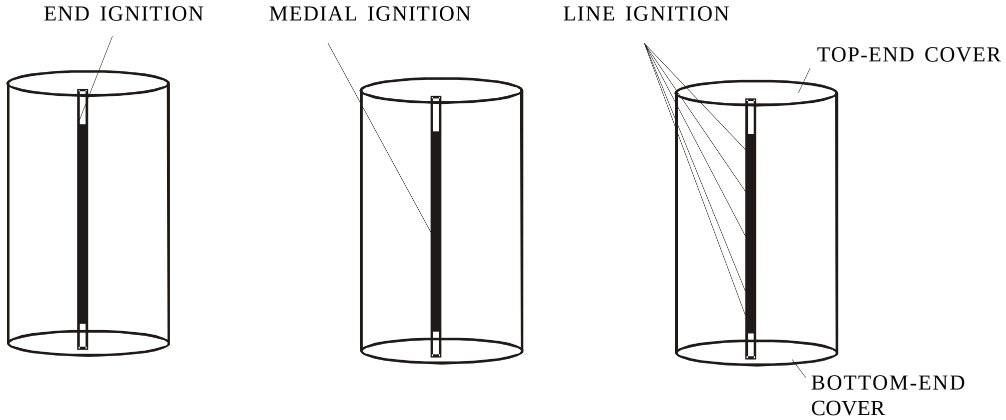


Figure 2. Three types of ignition methods of central HE.

Deviatoric stress is:

$$S_{ij} = \sigma_{ij} + (p+q)\delta_{ij} \tag{4}$$

Hydrodynamic pressure is:

$$p = -\frac{1}{3}\sigma_{kk} - q \tag{5}$$

JWL state equation for explosive detonation production is:

$$p = A_1\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B_1\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} \tag{6}$$

where P is the explosive gas pressure, V is the explosive gas volume, E is the unit volume explosive energy; A_1, B_1, R_1, R_2, are the JWL state equation parameters, respectively. For TNT, A_1 = 371.2 GPa, B_1 = 3.231 GPa, R_1 = 4.15, R_2 = 0.95, ω = 0.30, and $E = 7.0\times10^9$ J/m^3.

Gruneisen state equation was used for the fuel. That is:

$$p_f = \frac{\rho_0 C^2 \mu\left[1+\left(1-\frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1-(S_1-1)\mu - S_2\frac{\mu^2}{\mu+1} - S_3\frac{\mu^3}{(\mu+1)^2}\right]^2} + (\gamma_0 + a\mu)E \tag{7}$$

where p_f is the pressure in fuel medium; C = 0.148, S_1 = 2.560, S_2 = –1.980, S_3 = –0.226, γ_0 = 0.500, E = 0, $\mu = \frac{\rho}{\rho_0} - 1$, ρ_0 is the initial density of fuel; ρ is the instantaneous density of fuel, and $a = 0_o$

Using the above Eqns (1)-(7), the simultaneous displacement, velocity and acceleration can be found. Under the explosion drive of central HE, the FAE device shell and the fuel start to accelerate. The velocity distribution of fuel dispersal can be found by the numerical compute. In the computation, three kinds of ignition methods were studied. These are that the column central HE is ignited at the medial point, at the end and simultaneously on the axis, respectively. The end ignition means that the detonation wave propagates from the end of the central HE to another end. The medial ignition means that the detonation wave propagates in both directions from medial point to ends of the central HE. The line ignition means that the detonation wave propagates in a radii direction from the centre axis of the central HE.

The instantaneous velocity distributions for the end ignition, when the ratio between the heights of central HE and the FAE device is 0.64, is shown in Figs 3-4.

The instantaneous velocity distribution for the line ignition, when the ratio between the heights of central HE and the FAE device is 0.64, is shown in Figs 5-6.

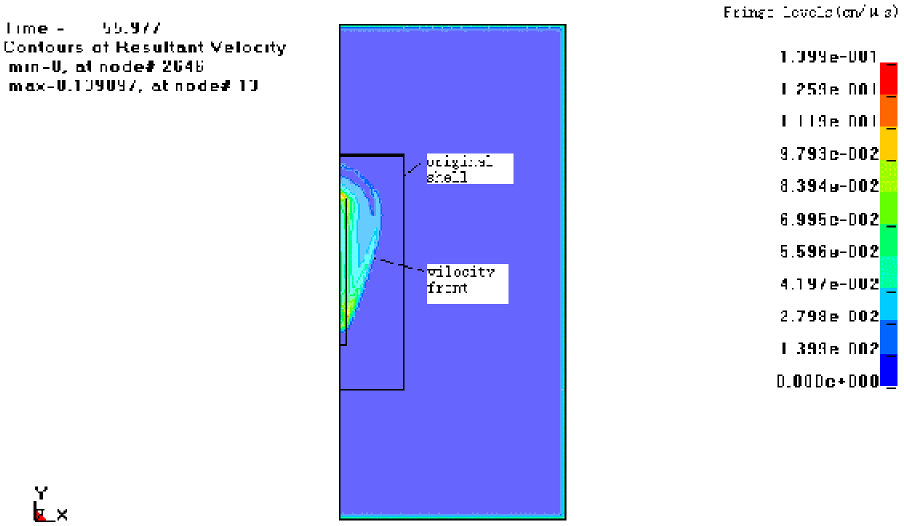


Figure 3. Fuel velocity distribution in case of end ignition at 56 ms (h/H=0.64).

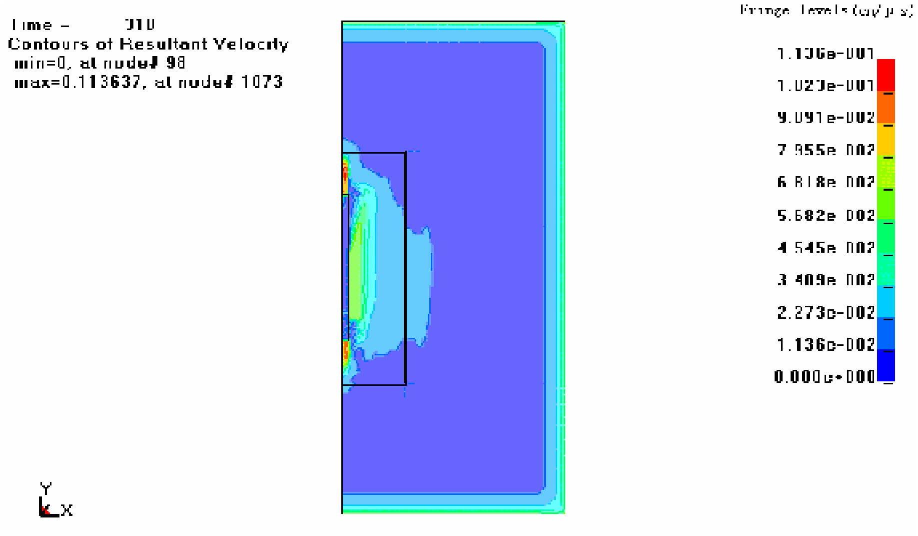


Figure 4. Fuel velocity distribution in case of end ignition at 310 ms (*h*/*H*=0.64).

The curve of velocity on the end cover of an FAE device versus time at the positions on the radius of the end cover are shown on Fig. 7 for end ignition. R is the radii from the centre axes of the FAE device.

The peak velocities change with distances on the end cover is shown in Table 1 and Fig. 8, when the ratio between the heights of central HE and device is 0.64. Radii in Table 1 is the distance from the centre to some point on the end cover. The fuel dispersal velocity on the top-end cover is symmetrical to that on the bottom-end cover in both the cases of line ignition and medial point ignition. The velocities on the top-end cover corresponding to the start end of the central HE and those on the bottom-end cover corresponding to the terminal end of the central HE is dissymmetrical in the case of end ignition.

Table 1. Fuel dispersal peak velocities on top-end cover vs radius (m/s) *h*/*H*=0.64

R (cm)	0	10	20
Line ignition	290	115	45
End ignition	259	125	41
Medial point ignition	180	105	63

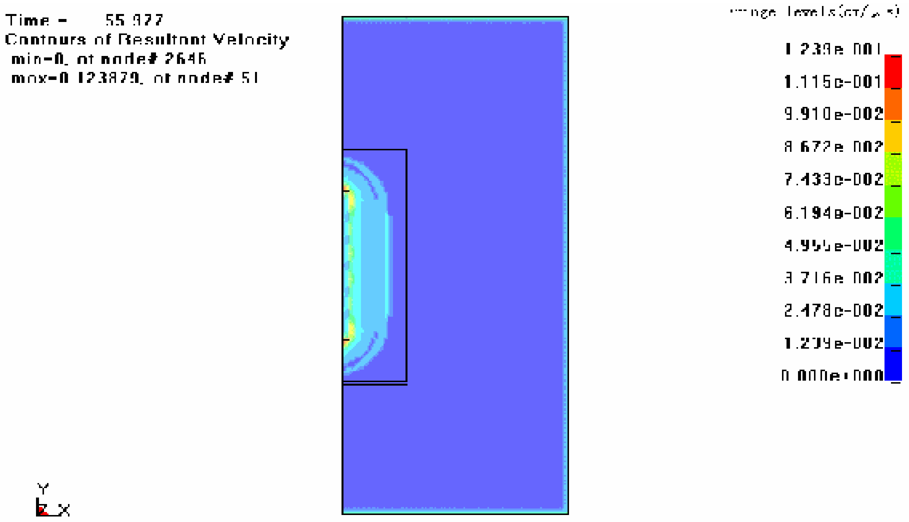


Figure 5. Fuel velocity distribution in case of line ignition at 56 ms (*h*/*H*=0.64).

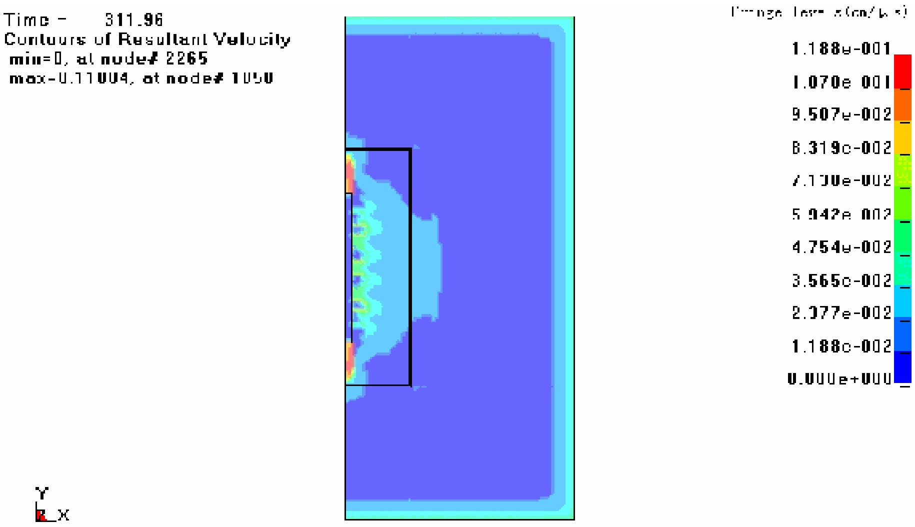


Figure 6. Fuel velocity distribution for line ignition at 312 ms (*h*/*H*=0.64).

The velocities distribution versus radii on both end covers of a device is more uniform in case of the end ignition. In other words, the differences of velocities at the various positions on the end covers are less.

The fuel dispersal velocities distributions on the shell side wall are shown in Fig.8 and Table 2. In Table 2, *y* is the height from the bottom-end cover to some point on the shell side wall. In Fig. 8, curve 1 is the velocity distribution versus *y* in the case of medial ignition, and curve 2 is the velocity distribution in the case of line ignition. The dispersal velocity near the middle part of shell side wall is larger in the case of medial ignition than that in the case of line ignition (Fig. 8). The dispersal velocity distribution on the shell side wall is more uniform in the case of the line ignition. But it is difficult to ignite on axis of the central HE in practice.

The similar compute results to Table 2 (*h*/*H*=0.64) can be obtained when the ratio between the heights of central HE and device, *h*/*H*, is 0.73 and 0.89 by the numeral compute.

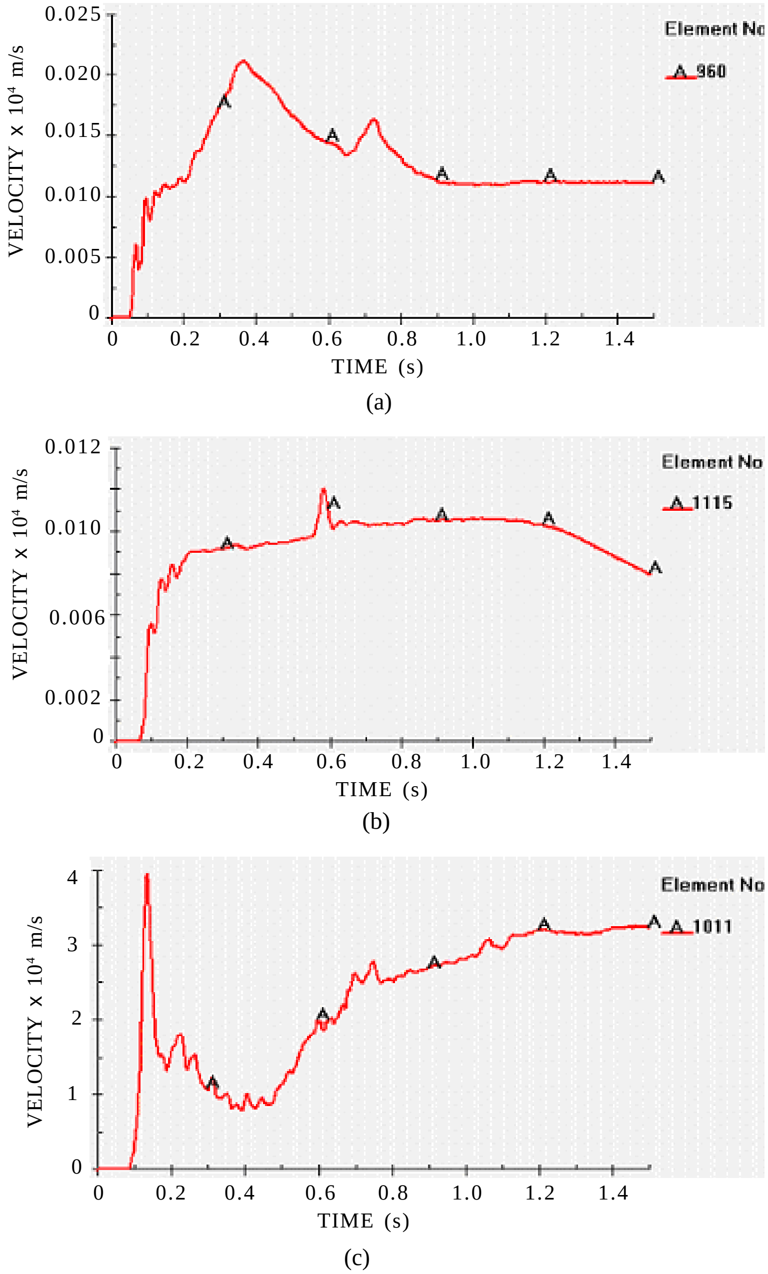


Figure 7. Fuel velocity on end cover versus time for end ignition (h/H=0.64) at radius (a) 2.25 cm, (b) 9.48 cm, and (c) 19.70 cm from the central axes of the FAE device.

The influence of the central HE height on the dispersal velocities on the end covers is shown in Table 3. The influence of the central HE height on the dispersal velocities on the shell side wall is shown in Table 4.

4. EXPERIMENT

The fuel dispersal velocity was measured by the use of high-speed movement analysis system, as shown in Fig. 9. In the experiment, the central HE column was ignited at the end. The height and the diameter of the FAE device are 0.7m and 0.4m, respectively. The height ratio of the central HE and the device is 0.73. The materials of the FAE device shell and fuel are the same as those in the numeral compute. From the measure results (Fig. 9), one can see that the fuel dispersal velocity distribution tends on the shell side wall and the end cover

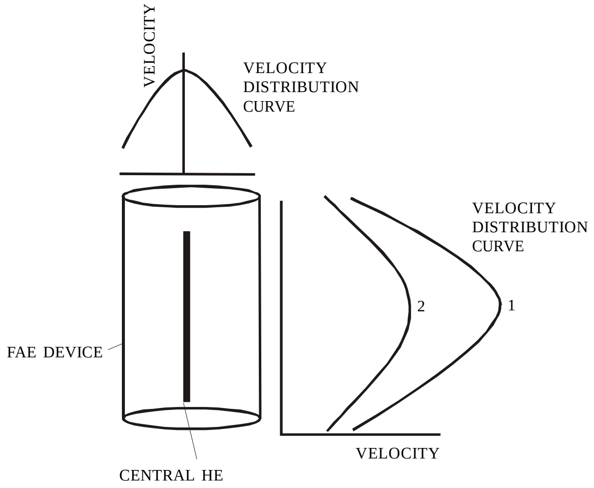


Figure 8. Fuel dispersal velocities distributions on the shell side wall: curve 1 at medial ignition; curve 2 at line ignition.

agree with the numerical compute results. By the measure results, one can obtain that the peak-dispersal velocity (that is maximal velocity value on the curve of velocity versus time) on the end cover is 299 m/s, near the axis of the FAE device, and the peak dispersal velocity on the shell side wall is 250 m/s, near the middle part of the shell side wall in the height direction of the FAE device.

Table 2. Fuel dispersal peak velocities on side wall (m/s) (*h*/*H* = 0.64)

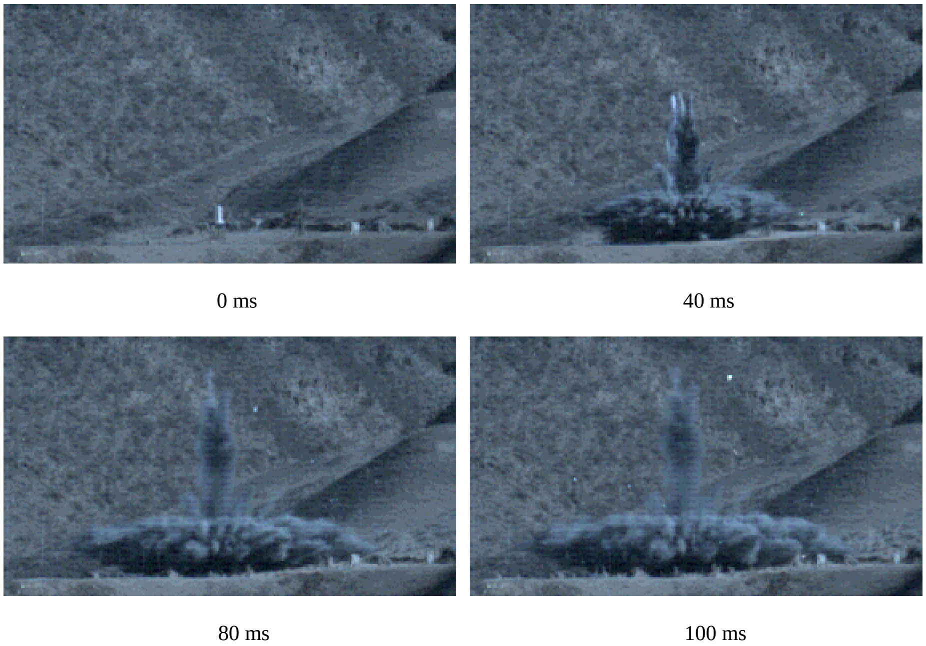
y (cm)	12	35	58
Line ignition	174	225	174
End ignition	182	256	193
Medial point ignition	180	295	180

Table 3. Fuel dispersal peak velocities on top-end cover versus *R* in case of endignition (m/s)

R (cm)	0	10	20
$h/H = 0.89$	472	215	51
$h/H = 0.73$	278	131	42
$h/H = 0.64$	263	125	41

Table 4. Fuel dispersal velocities on shell side wall in case of end ignition (m/s)

y (cm)	0	35	70
$h/H = 0.89$	82	208	46
$h/H = 0.73$	71	242	43
$h/H = 0.64$	63	251	40



0 ms

40 ms

80 ms

100 ms

Figure 9. Fuel dispersal process measured with high-speed movement analysis system.

5. CONCLUSIONS

The influences of the central HE column height, and its ignition method on the fuel dispersal velocities were investigated by the numerical compute. From the computation results, one concludes that the dispersal velocities on the end covers near the central axis are larger in the case of line initiation. The dispersal velocity distribution along radius on both ends of the cylindrical FAE device has larger grads. Comparing the line ignition with end ignition, the dispersal velocity on the shell side wall is larger in case of the end ignition, when the central HE column height is less than 0.73 times than that of the shell height.

The numerical computation results showed that the dispersal velocity on both ends of the cylindrical FAE device depends on central HE column height. The higher is the central HE column, the larger the dispersal velocities on both ends of the cylindrical FAE device near the central axis of the device. The dispersal velocity on the shell side wall changes rarely with the central HE column height for the given central explosive mass.

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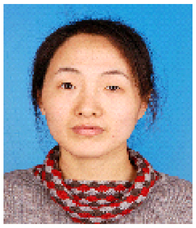

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