Detonation in Suspended Aluminum Dust in Tubes

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1. Introduction

Aluminum dust detonation in tubes is analyzed with two-phase flow model. The differences of velocity and temperature between gas and particles are considered. The dissipation by the convective heat transfer and viscosity through tube wall was taken into account. The criterion of ignition of aluminum particles in detonation waves is a new one that as the temperature of particle reaches aluminum melting point 931.7K and all the aluminum in particle is melted, the particle is ignited and chemical reaction begins. Development and propagation of aluminum dust detonation is numerically simulated. Velocity of detonation and ignition distance of particles is obtained. The distribution of pressure, density, velocity and temperature in the flow field of detonation wave is also obtained. Development and propagation of aluminum dust detonation with diameter 3.4μm and 5μm of particle in tube with inside diameter 15.2cm is numerically simulated. The detonation velocity and ignition distance of particles from the calculation are compared with experimental results. Also, detonation in aluminum dust with difference concentration is numerically simulated. Lower limit of detonation in aluminum dust is determined from calculation.

2. Model

As a shock wave propagates into a two-phase system with suspended aluminum particles in air, gas with high temperature behind shock waves makes the temperature of aluminum particles elevated and ignited, release energy to support the propagation of shock waves, then self-sustained detonation is developed.

It is assumed that detonation wave is one-dimensional. Aluminum particles are distributed uniformly in fluid field. The particles dispersed in gas behave as a continuous medium. The collision between the droplets can be neglected. Two phases have their own state variables such as density, velocity, internal energy. Each phase obeys conservation laws, but there are inter-phase exchange terms of mass, momentum, energy in conservation equation. The energy released from chemical reaction is absorbed only by gaseous phase. The temperature and pressure of all the gases in mixture are same. The dissipation by the convective heat transfer and viscosity through tube wall was taken into account.

In calculation it is assumed that aluminum particles can be ignited behind shock waves at the melting point of aluminum 931.7K and all of the aluminum of the particle is melted [1].

It is assumed that aluminum only reacts with oxygen. The reactant is $2Al+3/2O_2=Al_2O_3$. Product Al_2O_3 is liquid and its velocity and temperature is same as gas. In calculation, boiling point of Al_2O_3 is assumed to be 3800K. Here it is assumed that the temperature in detonation wave does not exceed the boiling point of Al_2O_3. If the temperature of product exceeds the boiling point of Al_2O_3 a part of aluminum oxide will decompose to aluminum in gas and oxygen to keep gas temperature to be 3800K.

The aluminum dust is ignited with high explosive in experiment. Here high explosive product is simplified as gas with high velocity and high temperature with total energy to be same as the total heat of explosion of high explosive.

3. Results

Figure 1 is the pressure in different time with equivalent ratio ϕ=1. Detonation velocity tends to be 1.62km/s. This is quite well agreement with Tulis' experimental result of 1.65km/s[2]. Ignition distance of aluminum particle is 3mm that is agreement with Tulis' experimental one with same detonation velocity. Distribution of density, velocity, temperature of gas and particle is also obtained.

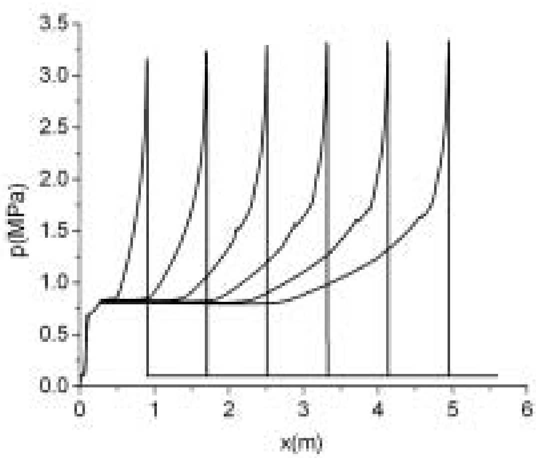

Figure 1. Pressure distribution at different time

Figure 2 is pressure history of detonation in aluminum dust with diameter 5μm. The pressure history is also calculated with ignition criterion of aluminum particle as its temperature reaches melting point of aluminum 2300K. Detonation fails to develop in calculation with this criterion. Tulis' experimental showed that detonation could happen as the particle diameter is 5μm. Detonation velocity was 1380m/s and ignition distance of aluminum particle was 19mm in his experiment. Detonation happens if ignition criterion is that aluminum particles can be ignited behind shock waves at the melting point of aluminum 931.7K and all of the aluminum of the particle is melted. The computational result is that detonation velocity is 1450m/s and ignition distance of aluminum particle is 17mm.

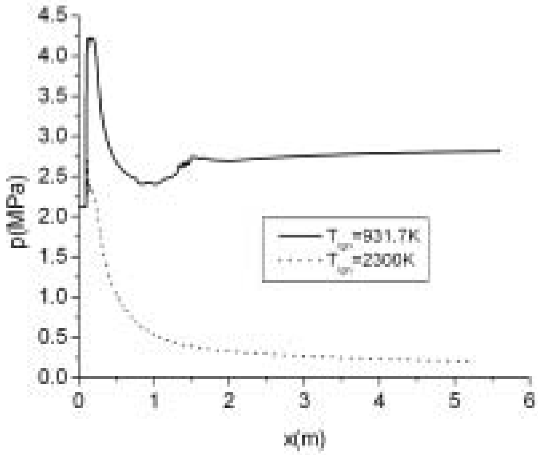

Figure 2. Pressure history of calculation with different ignition criterion

Figure 3 is pressure history of detonation in suspended aluminum dust in air in tubes with different equivalent ratio. As ϕ=0.24, pressure decreases as shock wave propagates and detonation does not occur. We may conclude detonation lower limit is ϕ=0.25 as the tube diameter is 15.2cm from the results of calculation.

The development and propagation of detonation is also numerically simulated as the tube diameter $D_h \to \infty$. $D_h \to \infty$ means the effect of friction and convective heat conduction of tube wall can be neglected. Figure 4 is the pressure history of detonation with different equivalent ratio. From the results of calculation the detonation lower limit is ϕ=0.16.

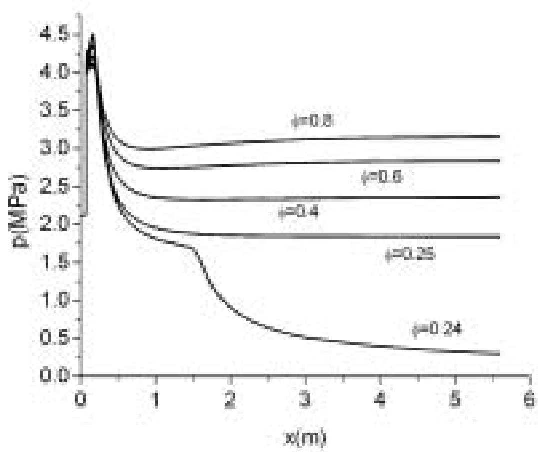

Figure 3. Pressure history of detonation in tubes with diameter D_h=15.2cm

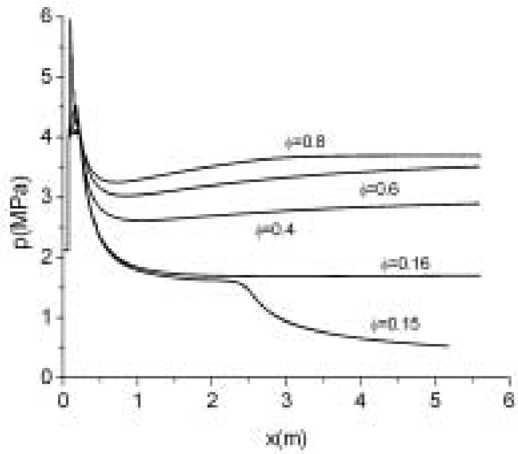

Figure 4. Pressure history of detonation in tubes with diameter $D_h \to \infty$

References

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2. Tulis A.J., Selman J. R., Detonation Tube Studies of Aluminum Particles Dispersed in Air, 19th International Symposium on Combustion, The Combustion Institute, 1982, 655-663