Fuel 228 (2018) 112–122

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Explosion energy of methane/deposited coal dust and inert effects of rock dust

Yifan Song, Bouras Nassim, Qi Zhang*

State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China

ARTICLE INFO

Keywords:
Deposited dust
Flame temperature
Flame velocity
Pressure wave
Suppression effect

ABSTRACT

In order to study the processes of lifting, dispersing and igniting of a dust layer behind the local gas explosion as well as their suppression, premixed methane local explosion igniting deposited coal/inert rock dust at the bottom of a tube are simulated. The two-phase combustion mechanism is obtained that the deposited dust is kicked up by the leading pressure wave, developing an uneven dust cloud filling in the tube, and then the gas flame ignites the dust cloud to form the composite flame. The rock dust lain on the tunnel ground has a significant suppression effect on the explosion overpressure, flame temperature and velocity of methane with coal dust. When the rock dust proportion in coal dust is 90%, the peak values of overpressure, flame temperature and flame velocity of the hybrid coal dust/rock dust/methane explosion are 0.6, 0.78 and 0.55 times of those of coal dust/methane explosion, respectively. The rock dust with the particles of smaller size has a remarkable suppression effect on explosion flame. When the rock dust proportion in the coal dust is 70%, the peak explosion overpressure and the flame velocity under suppression of the 12 μm rock dust are 10% and 11% lower than those of the 31 μm rock dust, respectively.

1. Introduction

Methane and coal powder are applied widely in industry fuel. In China, gas explosions in the process of coal mining often occur. Compared with pure methane in air, the explosion reaction for methane with coal dust participates in air can cause more serious disaster effects in the accidents [1,2]. The laying of inert rock dust on the tunnel ground is the main method to suppress the gas/coal dust explosion [3]. The inhibition effect of rock dust on the gas/coal dust explosion is related to the particle size, amount of rock dust lain on the ground, and explosion intensity. However, very few literatures quantitatively assess the inert effects of rock dust on the explosion energy and study the dynamic interaction between inert dust and combustion flame. The effects of minimum ignition energy, dust concentration, particle size and others have been mainly investigated through experiments in small pipes and tanks [4–9]. Coal dust explosion experimented by Man et al. [10] in the 20 L chamber showed that the particles (> 53 μm) were generally more difficult to ignite, and the minimum ignition concentration increased with decrease in O_2 level. Li et al. [11] used a 20 L spherical explosion vessel to study the explosibility characteristics of coal dust, and found that the maximum pressure and maximum rate of pressure rise showed an increasing trend as the size dispersity and the particle size of coal dust decreased, simultaneously, 250 g/m^3 was discovered as the optimum explosion concentration mostly in all explosion conditions.

However, the explosion of the hybrid mixtures presents a different characteristics from those of either gas or dust explosion. Introducing that coal dust can increase the ignition delay time, furthermore, the smaller the coal particle size the longer the ignition delay time [12]. Garcia-Agreda et al. [13] reported and observed the non-linear and synergistic effects of dust/gas mixture explosions, and obtained that the volatile content of the dust significantly affected the minimum explosive concentration. In addition, Addai et al. [14] studied the addition of small amount of combustible dust (concentration below the minimum explosible concentration) could decrease the minimum ignition temperatures of flammable gas. It should be noted that due to the pressure and flame acceleration in the geometries with high L/D ratios [15], the characteristics of dust explosion in the pipeline are different from those in the tank. Semenov et al. [16] developed a mathematical model for combustion of coal particles and dust-layered detonation formation in a tube which suggested the Magnus force as the main action to lift dust. Liu et al. [17] carried out explosions of coal dust samples with different particle concentrations in a horizontal experimental tube of length 29.6 m, and found that the concentration of coal dust for obtaining an explosion that propagated along the tube was between 120 g/m^3 and 960 g/m^3. Houim et al. [18] numerically

* Corresponding author.
E-mail address: qzhang@bit.edu.cn (Q. Zhang).

https://doi.org/10.1016/j.fuel.2018.04.155
Received 27 January 2018; Received in revised form 23 April 2018; Accepted 27 April 2018
0016-2361/

Nomenclature

a	Absorption coefficient, m^{-1}
$\overline{A}$	Pre-exponential factor in the Arrhenius formula, $(m^3 \cdot kg)^{1/2} \cdot s$
A_p	Surface area of the particle, m^2
A_{pn}	Projected area of particle n, m^2
c_p	Heat capacity of the particle, J/kg·K
$c_{p,i}$	Special heat of precipitating volatile matter, J/kg·K
C_D	Drag coefficient, dimensionless
C_{EBU}	Correction factor, dimensionless
$C_{1\varepsilon}$	Constant in the model, 1.44
$C_{2\varepsilon}$	Constant in the model, 1.92
d_{coal}	Coal particle diameter, m
$D_{i,m}$	Diffusion coefficient for species i in the mixture, m^2/s
d_p	Particle diameter, m
d_{pn}	Diameter of the nth particle, m
E	Activation energy, J/mol
f_h	Fraction of reaction heat given to solid, dimensionless
f_{pn}	Scattering factor of particle n, dimensionless
F_D	Drag force acted on the particles, N
F_x	Other forces acted on particles, N
G	The incident radiation, W/m^2
h_{fg}	Latent heat, J/kg
$\hbar$	Convective heat transfer coefficient, $W/m^2 \cdot K$
h_{pyrol}	Heat of particle pyrolysis as volatiles, J/kg
h_{reac}	Heat of particle surface reaction, J/kg
k	Turbulent fluctuations kinetic energy, J
L	Maximum element size, m
m_a	Ash content in the particle, kg
m_p	Mass of the particle, kg
$\overline{m_p}$	Average mass of particles in the control volume, kg
$m_{p,0}$	Initial mass of particles, kg
$\dot{m}_{p,0}$	Mass flow rate of the particles, kg
Δm_p	Mass change of particles in the control volume, kg
$m_v(t)$	Volatile yield up to time t, kg
k_{eff}	Thermal conductivity of gas mixture, W/m·K
p	Pressure, Pa
R	Universal gas constant, 8.314 J/mol·K
Re	Reynolds number, dimensionless
R_i	Net rate of production of species i by chemical reaction, $kg/m^3 \cdot s$
S	Deformation tensor, m/s^2
S_{coal}	Specific surface area of coal particles, m^2
Sc_t	Turbulent Schmidt number, dimensionless
S_h	Chemical reaction source term, $W \cdot kg/m^3 \cdot mol$
S_i	Rate of creation by additional sources, $kg/m^3 \cdot s$
S_m	Mass added to the continuous phase from the particle phase, $kg/m^3 \cdot s$
T_p	Particle temperature, K
T_{pn}	Temperature of particle n, K
T_∞	Local temperature of the continuous phase, K
ΔT_p	Temperature change of particles in the control volume, K
u	Instantaneous value of the fluctuating gas flow velocity, m/s
$u_i u_j$	Sreamwise velocity of fluid, m/s
u_p	Velocity of particles, m/s
Y_{coal}	Mass fraction of coal dust, dimensionless
Y_{O_2}	Mass fraction of oxygen, dimensionless
Y_M	Contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate, $kg/s^3 \cdot m$

Greeks

α_k	Inverse effective Prandtl numbers for k, dimensionless
α_ε	Inverse effective Prandtl numbers for ε, dimensionless
α_1	Yield factors, dimensionless
α_2	Yield factors, dimensionless
δ_{pn}	Scattering factor of particle n, dimensionless
ε	Turbulent fluctuations kinetic energy dissipation, m^2/s^3
ε_p	Particle emissivity, dimensionless
θ_R	Radiation temperature, K
λ	Step length factor, 20
μ_{eff}	Total flow viscosity in flow, Pa·s
ρ	Density of gas mixture, kg/m^3
ρ_p	Density of particles, kg/m^3
σ	Stefan-Boltzmann constant, 5.67×10^{-8} $W/m^2 \cdot K$
$(\tau_{ij})_{eff}$	Deviatoric stress tensor, W/m·K

demonstrated that the structure of the flame is analogous to that of a turbulent and non-premixed flame in a tube, and most of the oxygen is consumed from carbon char.

One of the usual ways to mitigate the combustion hazard caused by fuel dust is to spread inert dust. Dastidar et al. [19] and Johnston et al. [20] both have investigated the inert dust suppression effect quantity on explosion pressure. Numerical simulation has become an effective method for studying explosion suppression. Spath et al. [21] numerically obtained that the powder suppressant could effectively control the explosion pressure and flame meanwhile. Krasnyansky et al. and Klemens et al. conducted a lot of simulation investigations and concluded that the main contributing factors of explosion suppression included inert particle types, particle diameters, particle concentrations and particle dispersion states [22–24].

In order to investigate the energy output process of two-phase explosion, it is necessary to monitor the parameters which reflect the

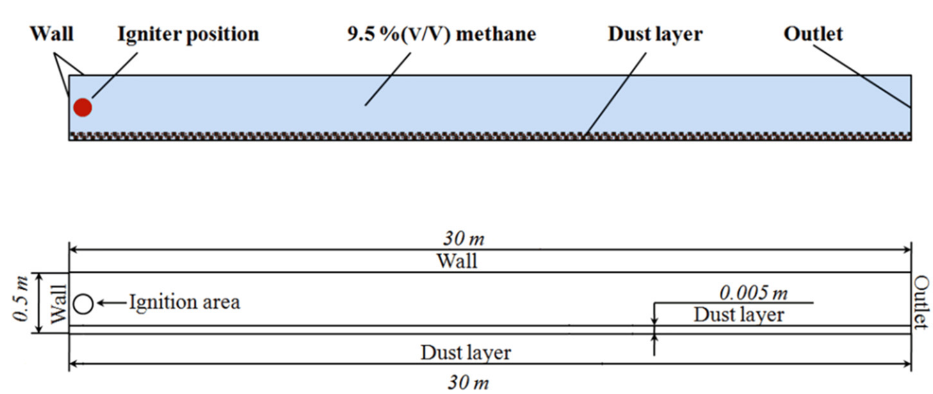

Fig. 1. Schematic diagram of model.