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The Temperature Profile of Rectangular Fuel Source Jet Fire with Different Aspect Ratio

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Abstract

With more and more natural gas has been transported by pipelines, the possibility of natural gas jet fire caused by inner or outer factors is increased gradually. That will result in casualties and domino effect to make further disaster and serious loss of property. It is imperative to study jet fire and prevent jet fire happening. This paper investigates the temperature profile for square and rectangular fuel nozzle (long side sets along transverse) horizontal jet fires. The numerical simulation code was carried out to simulate jet fires with different jet velocity varied from 27.5 m/s to 205.8 m/s. The fuel leak area for square and rectangular was same (400 mm^2), but the aspect ratio (width / length, W/L) were 1:1 and 1:4, respectively. Results show that the temperature increase with the jet velocity, and the relationship between maximum temperature along centreline and jet velocity is closed to line which slope is 1.82. The simple function for this connection was established. The maximum temperature of vertical direction locates at 1m from centreline, and the maximum temperature increase with jet velocity. The temperature along centreline for rectangular flame is less than square flame at same point and the high temperature area along horizontal direction is less. It is deduced the rectangular nozzle results in flame shorter and more width due to larger relative surface area and air entrainment. The high temperature area in transverse direction for rectangular nozzle is greater than square.

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Keywords: jet fire, aspect ratio, temperature, rectangular fuel source, fire safety

Nomenclature

f	External force vector (kg/s^2/m)
h	Sensible enthalpy (kJ/kg)
p	Pressure (Pa)
q	Conductive and radiate heat fluxes (kW/m^2)
R	Universal gas constant (J/(mol▪K))
t	Time (s)
u	Velocity vector (m/s)
W	Molecular weight of the gas mixture (kg/mol)
y	Width (m)
C_p	Specific heat of air at constant pressure
C_T, C_1	Constants
Q	Theoretical heat release rate (kW/m^2)
T	Ambient temperature (K)
$\triangle T$	Temperature rise above ambient (K)
Z	Height (m)

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Greek symbols	
β	Constant
ρ	Density (kg/m^3)
τ_{ij}	Viscous stress tensor (kg/s^2/m)
Φ	Dissipation rate (kW/m^3)
Subscripts	
0	Ambient
1	Per unit length
m	Centreline

1 Introduction

The fire accident of natural gas caused by pipeline failure increases with the natural gas transportation pipeline increases. The fire accident of leakage gas not only results in serious damage but also domino effect. On the basis of API581 [1], the jet fire accident after gas pipeline broken is major damage for gas pipeline transportation. A historical survey shows that 50% of jet fire accidents will undergo at least one additional event [2]. Nowadays, many representative cases of jet fire were occurred, it is imperative to research for jet fire prevention. In Tivissa (Spain), the jet fire from a broken pipe in a road tanker originated flames with a length of more than 15m which finally lead to the tank explosion. In Barcelona [3], two of natural gas jet fire accidents with jet fires length approximately 10 m have happened in 2007–2008. In Chinese Daqing city, a natural gas jet fire with 6 deaths was occurred as pipeline ruptured, then the jet fire resulted in explosion in January 1, 2002 [4]. In order to maintain fire safety, it is necessary to research jet fire behavior and mechanism.

The jet fire characteristics and hazard are widely studied by many scholars few years ago. Quintiere and Grove [5,6] investigated the fire plume and proposed the empirical model to predict fire temperature. Zhang [7] found their model couldn't be applied to sub-atmosphere jet flame plume, the modified model was carried out and applicable to sub-atmosphere fire plume temperature prediction well. A series of experiments were carried out by Kessler [8] to investigate the effect of tank pressure on the jet fire characteristics including flame geometry and spreading velocity. Tong [9] evaluated the natural gas jet fire hazard area using simulation software. The large scale experiments were conducted by Barbara to investigate the flame length and width of jet fire, and the hazard area also analysed [10]. The vertical jet fire have been extensively studied by most scholars. Hu team designed a series of experiments including fire source shape and ambient pressure to investigate flame temperature distribution and flame geometries, some dimensionless analysis were carried out to deduce theoretical model [11-13]. Hooker[14] investigated the effect of wind on vertical jet fire by experiment in enclose and opening space. Experiments of jet fire were carried out in vertical propane sonic and subsonic jet fires by Palacios [15, 16] to research the flame shape and radiation. The horizontal jet fire research is relatively less, only few reports are for horizontal jet fire characteristics (flame length, flame width, temperature radiation) [17-19]. That is insufficient to reflect the mechanism of horizontal jet fire, especially for temperature distribution which is one of basic and important parameters.

In this paper, the numerical simulation code was carried out to investigate the temperature decay along jet direction of horizontal jet fire produced by rectangular fuel source with different aspect ratio and velocity. The effects of fuel jet velocity and rectangular fuel source aspect ratio on temperature distribution were analysed.

2 Theoretical model

Several empirical models for predicted characteristics of jet fire have been proposed, but little for temperature distribution. A centreline temperature rise $\triangle T_m$ model for vertical jet fire with line burner was suggested by Yuan [20] based on a series of experiments and literatures. The vertical and horizontal temperature rise models dependent on the height and width are shown in following, the Eq. (1) for vertical temperature rise and the Eq. (2) for horizontal temperature rise.

$$\frac{\Delta T_m}{T_0} = C_T \left(\frac{Q_1}{\rho_0 C_P T_0 \sqrt{g}} \right)^{2/3} Z^{-1} \tag{1}$$

$$\frac{\Delta T}{\Delta T_m} = \exp\left(-\beta y^2 / \left(C_1 Z \right)^2 \right) \tag{2}$$

Where C_T varies from 2.38 to 2.6, 2.6 is wide used by most scholars. β is a constant varied from 0.64 to 1.50, and can be replaced by 1.23. Q_1 is heat release rate per unit length for line source, but for axisymmetric source is full heat release rate