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Numerical Study on the Spontaneous Combustion of High-density Polyethylene

Long SHI[a,*], Jun-hui GONG[b], Dong-mei HUANG[c], Xuan-ya LIU[d], Guo-min ZHANG[a]

[a] *Civil and Infrastructure Engineering Discipline, School of Engineering, RMIT University, VIC 3001, Australia*
[b] *College of Safety Science and Engineering, Nanjing Tech University, Nanjing, Jiangsu 210009, China*
[c] *College of Quality and Safety Engineering, China Jiliang University, Hangzhou, Zhejiang, 310018, China*
[d] *Tianjin Fire Research Institute of MPS of China, No. 110, South Weijin Road, Nankai District, Tianjin, PR China, 300382*

Abstract

Although non-charring polymers have been frequently utilized in the industry, public transport and buildings, their fire risk could be more serious comparing to the others such as timber fire. This is much due to the melting process in solid phase and also the high temperature and a large number of gas volatiles in gas phase. The numerical modeling of non-charring polymers could be complicated because of the difficulty in describing melting processes and in-depth radiation (for some transparent polymers). In this study, a numerical model was developed to predict the fire behaviors of a typical non-charring polymer (high-density polyethylene). The focus was on its fire behaviors under spontaneous ignition conditions, namely without the acceleration of spark plug. The model has considered both solid and gas phases, such as pyrolysis reactions, melting process, in-depth radiation, gas and liquid transportation inside the solid phase, and gas phase combustion. The numerical results for solid phase were validated by cone calorimeter experiment. For gas phase modeling, the predicted temperature and gas velocity are consistent with the major heat transfer processes.

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Keywords: non-charring polymer, high-density polyethylene, spontaneous combustion, pyrolysis modeling, melting process.

Nomenclature

A	pre-exponential factor (s^{-1})
C	specific heat capacity (J kg^{-1} K^{-1})
D	diffusivity coefficient (m^2 s^{-1})
E	activation energy (J mol^{-1})
H	specific enthalpy of material (J)
k	reaction rate (s^{-1})
M	molecular weight (g mol^{-1})
MLR	mass loss rate (g s^{-1} m^{-2})
n	order of reaction (-)
N	number of species
P	pressure (Pa)
$\dot{q}''$	heat flux (kW m^{-2})
Q	heat of reaction (J kg^{-1})
R	universal gas constant (J mol^{-1} K^{-1})
t	time (s)

* Corresponding author. Tel.: +63-3-9925-3215.
E-mail address: long.shi@rmit.edu.au / shilong@mail.ustc.edu.cn

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T	absolute temperature (K)
u, v	velocity (m s^{-1})
x, y	Cartesian coordinates (m)
Y	mass fraction (-)
Greek symbols	
γ	permeability (m^2)
κ	absorption coefficient (m^{-1})
Δ	change in variable value (-)
Δh	heat of reaction (kJ/kg)
Θ	production or reaction rate (kg m^{-3} s^{-1})
λ	thermal conductivity (W m^{-1} K^{-1})
μ	dynamic viscosity (Pa s)
υ	viscosity, stoichiometric coefficient
ρ	density (kg m^{-3})
ϕ	porosity (-)
Subscripts	
ext	external
f	flame
g	gas phase/species
i, j	species
l	liquid water
pyr	pyrolysis process
rad	radiation process
reac	reaction process
s	solid phase/species

1. Introduction

Fire risk of non-charring polymers is always a big concern for engineers and researchers as they have been extensively used in the industry, public transport and buildings [1-4]. Taking building as an example, they have been utilized as or as a part of wall, lining, floor, furniture, etc. Under the fire conditions, they can melt and transform into the liquid fuel when reaching their melting points. This kind of fire characteristics can largely promote the fire spread in buildings and endanger the occupants greatly. It is also known that fire involving non-charring polymers such as polyethylene is more hazardous than the others, which can be partly evidenced by the higher gas temperature [5] and pool fire [6, 7].

Ignition is the transition between pyrolysis and combustion, which can be classified into piloted and spontaneous ignition [8]. In piloted ignition, flaming is initiated by a pilot in a flammable vapor-air mixture exhausted from solid phase, while in spontaneous ignition flaming is developed spontaneously by heating the mixture. Although piloted ignition has been frequently investigated in the literature, less focus is on the spontaneous ignition of solid fuels [9]. This may be partly because it is more difficult to obtain repeatable results for spontaneous ignition [10]. The different fire behaviors under two ignition conditions can be reflected by several parameters such as the ignition time, volatile emission and minimum heat flux [11].

Challenges still exit for the numerical modeling of non-charring polymers. This is much dependent on their characteristics such as melting processes and low absorption coefficient. For example, a large portion of non-charring polymers can go through melting processes under high temperature, while at the top of the surface liquid fuel can be found when the temperature is higher than the melting point [12, 13]. Many previous numerical models have ignored the melting processes. In addition, as some non-charring polymers are transparent, external heat can penetrate into the solid by in-depth radiation [14, 15], not only by the usual way of thermal conductivity. The amount of absorbed heat is much dependent on the absorption coefficient of the material itself.

Therefore, in this study, a typical non-charring polymer, namely high-density polyethylene (HDPE), was investigated both experimentally and numerically under spontaneous ignition conditions. A comparison between the fire behaviors under spontaneous and piloted ignition was also carried out to benefit the practical applications of fire risk evaluation.