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Review

Combustion and flame spread on fuel-soaked porous solids

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ABSTRACT

Fires caused by accidental spillage of flammable liquids have been a major safety concern in industries and urban areas. There has been a recent surge of interest in the research concerning the combustion and flame spread over an inert porous media soaked with flammable liquid. This interest has been driven by the need to better understand fire and its behaviour under these conditions and improve the relevant fire safety and prevention technologies. A review of key studies in this subject area has been conducted and summarised, focussing mainly on the theory plus a notable experimental findings about combustion and the flame spread phenomena of fuel-soaked porous media. The review covers topics such as flame spread behaviour, physical flame propagation aspects, heat transfer, temperature distribution; and fuel consumption over inert porous media. The review concludes with some practical safety and environmental considerations for decontamination of land soaked with flammable liquid.

Contents

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Nomencluture

V_f	flame spread rate
T/C	thermocouple
T_{st}	stoichiometric temperature
d_p	particle diameter
d_{min}	minimum particle diameter
T_{st}	stoichiometric temperature
H	height
δ_u	thickness of flammable gas layer
V_a	airflow velocity
T_{flash}	flashpoint temperature
T_{fire}	fire point temperature
T_s	porous solid temperature
μ	viscosity
V_s	fuel supply
C_p	specific heat
ρ	density
k	thermal conductivity
ρ_l	liquid fuel density
g	gravitational acceleration
D_f	diameter of the flame pillars
σ_{si}	surface tension
D_{bed}	bed diameter
f	flame fluctuation frequency
L	reverse flow dimension
t_s	fuel supply time
t_f	fuel consumption time
Q_{Total}	total heat release rate
ΔHR	heat of reaction
$\dot{m}$	mass flow rate
α	thermal diffusivity

1. Introduction

Fire is man's oldest and perhaps the most important invention. It provided him with his first source of energy; light and warmth and enabled him to work with metals. Despite its importance, fire is a major cause of human suffering and material loss, and its impacts on the environment are countless [1–5]. The cost of accidental fires in Australia alone represents approximately 0.8% of the GDP [1]. Similar figures have been reported in other parts of the world [6].

Among the various types of accidental fires, those due to spillage of flammable liquids in process industries are of significant importance as they can lead to significant direct and indirect losses [7]. Given that such spillages usually take place over concrete slabs, there has been a growing interest in field of fire safety to examine the combustion of liquid fuels over porous inert media. The interest has been motivated by the needs of the process industry to develop safer chemical processes whilst complying with increasingly stringent emission/pollution regulations.

Generally, fire is the most poorly understood phenomenon in science and engineering. Among the classical problems in the field of fire safety science itself, flame spread over porous solids soaked with combustible liquids (typically hydrocarbons) is even less understood. This can be partly attributed to the complexity of the fire itself which originate from its multi-disciplinary nature as well as the complex nature of interactions among the porous solid, liquid fuel and the flame [8]. If the spread of flames due to such fires is not controlled at early stages, it may result in a sustained flame front enveloping the entire plant, in turn, leading to severe loss of human life and property damage [6,9].

This review article is a critical examination of our current understanding of flame spread over porous solids under conditions pertinent to industrial fires and describes the related experimental and theoretical research. The review is divided into 5 sections. The first section provides (i) a brief description of the flame spread, (ii) a classification of diffusion flames spreading over different types of combustible materials, (iii) an overview of most widely used measuring techniques for characterisation of flame spread behaviour; and (iv) an examination of porosity and permeability concepts for porous media. It also summarises the key findings of past studies in a consolidated tabulated format. Section 2 begins with a brief statement about the mechanism of flame spread followed by a discussion about the rate of flame spread over inert porous solids (such as sand, soil, and etc.) soaked with liquid fuels. This section also examines the reciprocal effects of porous solids characteristics and the rate of flame spread. Section 3 briefly describes the characteristics of liquid fuel (flashpoint and viscosity) and the effects of these properties on the rate of flame spread. In Section 4 the mechanism of heat transfer, temperature distribution, fuel consumption and residual fuel are discussed. The physical features of flame spread are reviewed in Section 5. Finally, key safety recommendations are provided.

2. What is the flame spread?

Before explaining the mechanism of flame spread it is appropriate to give a brief explanation about the term 'flame spread'. Here, the word 'flame' refers to a relatively small scale fire or