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A review of physics and correlations of pool fire behaviour in wind and future challenges

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ABSTRACT

This paper reviews the physics and correlations for the burning behaviour of pool fires in wind, discussing also challenges for future research on this topic. In the past decades, the burning behaviour of pool fires in still air, which is solely buoyancy driven, has been extensively studied. These studies are primarily focused on scale, radiation, soot, pressure and gravity effects. However, these phenomena and physics change significantly with much more complexity in the presence of wind, with regard to heat feedback and burning rate; flame morphological characteristics; flame turbulence, soot and radiation emission. Remarkable progress has been made in understanding the behaviour of the heat feedback and burning rate, flame tilt, flame length and flame base drag of wind-blown pool fires. Several semi-empirical correlations have been proposed for these quantities, based on experimental data and the physically dimensional analysis. However, for wind-blown pool fires, the flame soot and radiation emission coupling with complex flow turbulence scales due to the interaction of buoyancy with wind still require more basic research. All these processes are more challenging especially for wind-blown large scale pool fires, which require knowledge and understanding of the physics, especially for establishing evaluation methodologies of their hazard and adverse impact.

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Nomenclature

A_e	area around the flames available for entrainment up to a height Z [m^2]
B	fuel mass transfer number (Spalding number) [–]
c_p	specific heat at constant pressure [kJ/(kgK)]
$D(d)$	pool diameter (side length) [m]
ΔD	flame base drag length [m]
Fr	Froude number [–]
Fr_w	wind speed Froude number [–]
f	flame pulsation frequency [Hz]
g	gravitational acceleration [m/s^2]
H	flame (vertical) height [m]
ΔH_c	heat of combustion of the fuel [kJ/kg]
l_f	flame length [m]
L	length of linear fire source [m]
$\dot{m}''$	mass burning rate per unit area [kg/(m^2s)]
$\dot{m}''_0$	mass burning rate per unit area with no wind [kg/(m^2s)]
$\dot{m}_{ent}$	air entrainment mass flow rate [kg/s]
$\dot{m}_f$	fuel mass supply rate [kg/s]
M_{fuel}	molecular weight of the fuel [kg/mol]
M_{o_2}	molecular weight of the oxygen [kg/mol]
n	fire source aspect ratio ($n = L/W$) [–]
$\dot{Q}$	heat release rate [kW]
$\dot{Q}^*$	non-dimensional heat release rate [–]
Ri	Richardson number [–]
Re	Reynolds number [–]
r^*	equivalent radius [m]
S	burner surface area [m^2]
St	Strouhal number [–]
T_∞	ambient temperature [K]
ΔT_f	flame temperature rise above ambient [K]
u	wind speed [m/s]
u^*	non-dimensional wind speed [–]
V	characteristic flow up-rising velocity [m/s]
W	width of linear fire source [m]
$Y_{o_2,\infty}$	local oxygen mass percentage concentration [23.2% in standard pressure]
Z	height above fire source [m]

Greek

χ	heat feedback fraction [–]
θ	flame tilt angle [degree]
ρ_∞	ambient air density [kg/m^3]
ρ_g	density of fuel gas (vapor) [kg/m^3]
ξ	mixture fraction [–]
μ	viscosity coefficient [kg/(ms)]
$\Delta\rho$	density difference [kg/m^3]
ρ_g	fuel vapor density [kg/m^3]

subscripts

conv	convection
fuel	fuel

1. Introduction

Pool fire, defined as a diffusion flame established on top of a horizontal fuel surface [1–8], presents problems of both fundamental and practical significance. Pool fire burning in still air is controlled by buoyancy alone (Fig. 1a). Extensive studies have been carried out in pool fires focusing on burning rate [2,9–40], air entrainment [10,41–50], flame height and pulsation [39,51–69] and soot production and radiation [9,10,15,16,40,70–98]. Among these works, a large number of studies have also been performed on buoyant diffusion flames above gaseous burners [43,51–54,56,71–76,78,79] wherein the heat release rate can be specified.

However, pool fire disasters occur mostly in open space involving the environmental wind commonly. Pool fire behaviour is then driven by the coupling of buoyancy and wind (Fig. 1b). In addition to changing the flame geometry by tilting it, cross wind will also affect the heat feedback mechanisms (conductive, convective, radiative), as well as the fuel-air mixing for this mixed buoyancy and boundary layer diffusion combustion. This has led to several correlations of burning rate [2,99–131], flame tilt angle [107,132–142], flame length (height) [50,132,140,143–146] and flame base drag [130,131,135,143,147–155]. Besides, the soot production and radiation in the flames may also change with the impact of wind due to the change of turbulence scales and their associated time scales. Thus the behaviour of wind-blown pool fires is much more complicated than that in still air, being always a significant challenge.

This review elaborates the state of researches on the burning

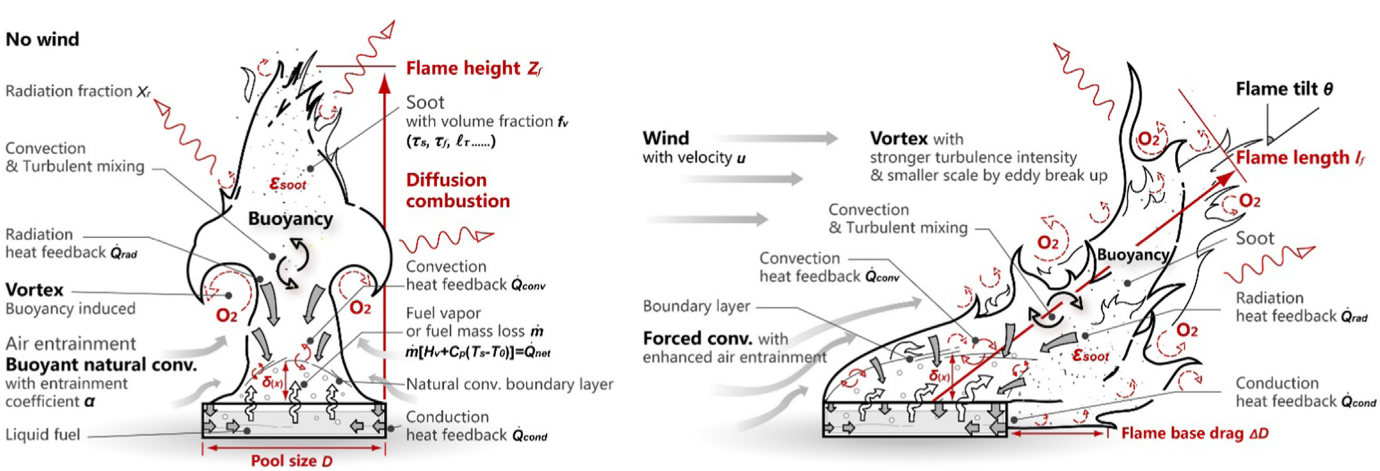

Fig. 1. The physics of a pool fire: (a) in still air; and (b) in wind.