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Establishing safety distances for wildland fires

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Abstract

In wildland fires, safety zones should be considered concerning people who are intervening in the emergency or attempting evacuation. To establish such zones, the solid flame model, together with the view factor calculated from a previously selected equation, was used to estimate the thermal radiation emitted by the flame front of a wildland fire. After determining the flame heights yielded by the 13 fuel types in the Rothermel classification for surface fires, and for crown fires in various Mediterranean forests, the thermal radiation was calculated for each scenario as a function of the distance. These data, together with threshold values for the vulnerability of people (protected or unprotected) and houses to thermal radiation, allowed for a set of safety distances for different situations to be obtained. These safety distances can be applied both in territory planning and in emergency situations.

Keywords: Wildland fire; Safety distance; Thermal radiation; Flames

1. Introduction

The mathematical modelling of wildland fires has traditionally had two main objectives: firstly, the prediction of the velocity at which a fire will spread and secondly, the estimation of the heat released from the flame front of the fire.

One of the most interesting possibilities of the prediction of the thermal radiation emitted by wildland fires is the establishment of safety distances, which allow for the definition of safety zones both for people (firefighters and the general population) as well as for houses and equipment. Within these safety zones, people extinguishing fires can work without endangering themselves and, furthermore, these zones provide safe evacuation routes. Such zones must be established on the basis of the thermal radiation that, in the event of fire, is foreseen to reach a given position, as well as on vulnerability data (maximum tolerable thermal radiation) for the people or equipment that will be subjected to the radiation.

Safety distances are widely used in a variety of fields for both preventive planning and emergency interventions. For example, they are commonly applied throughout the chemical process industry, not only in preventive terms in plant design (the minimum separation required between certain pieces of equipment in the event of a fire) and plant operation, but also in terms of emergency planning.

Though the concept of safety distances is also used in dealing with wildland fires, quantitative approaches to determining such distances have been addressed by very few authors. This is probably due to the fact that predicting the thermal radiation from wildland fires is more complicated and less accurate than in the case of hydrocarbon combustion (whose properties are usually much better defined). Furthermore, the features of wildland fires can change due to the ground features (slope) and meteorological conditions: for example, through mechanisms such as spotting, wind can propagate the fire to locations remote from the flaming front. Nevertheless, despite these difficulties, the establishment of safety distances can be highly useful in such fields as regional planning (in terms of the construction of houses or roads in or near forests) or emergency planning.

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Notation

E_p	average emissive power of the flame, kW/m^2
E_b	emissive power of the black body, kW/m^2
F	view factor, dimensionless
FB	fractional bias, dimensionless
H	flame height, m
L	flame length, m
$NMSE$	normalized mean square error, dimensionless
Q_r	radiative heat flux transmitted per unit area, kW/m^2
T_a	atmospheric temperature, K
T_f	flame temperature, K
u	wind speed, m/s
x	coordinate on the x-axis; distance, m
y	coordinate on the y-axis; distance, m
z	coordinate on the z-axis; distance, m

Greek letters

α	angle, deg (Fig. 2b)
β	angle, deg (Fig. 2b)
ε	flame emissivity, dimensionless
γ	angle, deg (Fig. 2b)
σ	Stephan–Boltzmann constant ($kW\,m^{-2}\,K^{-4}$)
τ	atmospheric transmissivity, dimensionless

A considerable research effort has been done in this field, and diverse authors have published quantitative proposals. Tran et al. [1] developed the ''Structure Ignition Assessment Model'' (SIAM), later discussed by Cohen [2]. Cohen and Saveland [3] applied this model to reduce the damage in the wildland–urban interface. Ahern and Chladil [4] analysed the damage from diverse bushfires as a function of distance. Gettle and Rice [5] proposed criteria for determining the safe separation between structures and wildlands. Butler and Cohen [6] proposed safety zones for firefighters (assuming them to be completely protected, including their necks and heads). These authors presented a theoretical model describing the net radiant energy transfer from a fire of a specific height to a standing firefighter; the predictions from the model were then compared to four cases of wildland fire entrapment, with good agreement. As a rule of thumb, they suggested a minimum distance between the firefighter and the fire of four times the average height of the flames; in a later paper [7], the same authors stated that their model underestimated thermal radiation within 10 m of the flame. Cohen [8] arrived at the conclusion that home ignitions were not likely unless flames and firebrand ignitions occurred within 40 m of the structure, although more recently the same author reduced this distance, as a general criterion, to 30 m [9]. There are also several other references, such as certain government regulations; the Generalitat (Autonomous Government) of Catalonia (1995) established a 25-m-wide perimeter protective zone in the wildland–urban interface for houses located less than 500 m from forests.

However, if one analyses all the information available in this field, it is evident that there is a significant gap concerning the specific design of safety distances or zones. This paper presents a methodology for establishing such distances on the basis of the conditions that could potentially influence fires: firstly, the type and condition of vegetation, and secondly, the worst meteorological conditions (in terms of atmospheric humidity and wind) that could reasonably be expected.

2. Prediction of thermal radiation

To determine safety distances, the heat flux from the fire must be known. In the case of wildland fires, an essential component of this is thermal radiation.

Convection is not usually taken into account concerning the effects on people and structures. As stated by Gettle and Rice [5], no references in technical literature suggest that convective transfer to structures would be as significant heat as radiative heat transfer from flames at a distance from a solid surface. Convective transfer is important to transfer heat to the canopy, but not from the point of view of heat transfer to structures located at a certain distance from fire.

A number of methodologies have been proposed for calculating the thermal radiation emitted by fires [5,10–14]. A method that has been used by some authors [6,15] in the field of wildland fires is the solid flame model. This model is widely used in the chemical process industry to predict the behaviour of hydrocarbon pool fires [16]. The authors' experience [17] with relatively large-scale fires of this type (of up to 28 m^2 in surface area) has confirmed the good results obtained when applying it. Therefore, the solid flame model was chosen for the estimation of the thermal radiation.

The solid flame model considers the visible flame to be a geometrical body that emits radiative energy uniformly throughout its entire surface area; the non-visible zones of the flame are usually not taken into account (in fact, these zones emit significantly less than the average radiation emitted by the visible flame). The thermal radiation reaching a target located a distance x from the flames is estimated using the following expression:

$$Q_r = E_p \tau F. \quad (1)$$

The emissive power of the flame (E_p) is the amount of heat emitted by the unit surface of the flame; it depends on the luminosity of the flame and can be estimated using theoretical or semi-empirical expressions [16]. It is