International Journal of Thermal Sciences 50 (2011) 2–11

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Monte Carlo estimation of thermal radiation from wildland fires

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ARTICLE INFO

Article history:
Received 4 May 2010
Received in revised form
8 September 2010
Accepted 14 September 2010
Available online 16 October 2010

Keywords:
Wildland fire
Radiation
Safety distance
Solid flame model
Monte Carlo method

ABSTRACT

As an alternative to the classical deterministic methods, a Monte Carlo method is proposed for the estimation of the radiant heat flux from wildland fires, and thus of fire-safe distances. The solid flame model is used, in which the flame is regarded as a uniformly-radiating surface with a simple geometry. Case studies are presented, ranging from the relatively simple case of planar or cylindrical flames to the case of the more complex geometries of irregular flame fronts where the strategy consists in approximating the front as a collection of individual solid flames. Model results are in good agreement with available data. An attempt is made to estimate the radiant heat flux ahead of a fire front spreading on a heterogeneous landscape. Finally the model is applied to determine the defensible space around a structure in which combustible vegetation has been totally cleared in the aim of reducing the wildfire threat to homes.

1. Introduction

Radiation heat transfer plays a key role in the preheating of fuels in forest fires, and therefore influences fire spread and behavior. Flame radiation is also very important in the context of firefighter safety and wildland–urban-interface fire problems [1]. The prediction of wildfire-induced radiation is therefore crucial and may provide a basis for establishing zones where people and structures are safe from fire. Notable contributions on this topic include Tran et al. [2], Butler and Cohen [3,4], Gettle and Rice [5], Sullivan et al. [6], Knight and Sullivan [7], and Zárate et al. [8]. Radiation prediction methods range from the very simple to the very complex. The latter invoke correlations and solutions to radiative transfer equations and computational fluid dynamics (see for example [1,9]). The paper of Sullivan et al. [6] provides a review of radiant heat flux models generally used for wildland fire purposes. More recently, Zárate et al. [8] have briefly described existing models and determined safety distances for different wildland fire scenarios. Both reviews show that a popular approach to the estimation of the radiation flux from wildland fires is the use of the solid flame model (SFM) together with the effective configuration or view factor in order to calculate the heat flux from the flame to a remote target. The SFM may be used when the thermal radiation heat transfer is significantly greater than other heat transfer mechanisms [10].

In the solid flame radiation model the visible flame is idealized as a solid body with a simple geometrical shape and with thermal radiation emitted from its surface (Fig. 1). The contribution of non-visible zones of the fire plume to the radiant heat flux is usually not taken into account. As shown by Wang [11], the validity of this assumption may be questionable for relatively intense wildland fires. However due to a lack of reliable data to estimate this contribution, this assumption is also made in the present study. The radiant heat flux per unit area reaching a remote target is given by $q = \tau FE$, where F is the view factor, E the emissive power of the visible flame, and τ the transmittivity of the gas layer between the flame and the target. The emissive power of the flame may be calculated as $E = \varepsilon E_b$ where ε is the effective emissivity of the flame and $E_b = \sigma T_f^4$ the blackbody emissive power at the flame temperature. The SFM is relatively simple, but it does require estimates of the atmospheric transmittivity and the emissive power of the flame. Estimates of the latter are especially prone to error [12]. Another source of error in the calculation of the impact of radiation on a target surface is the determination of the view factor, i.e. the proportion of the total energy emitted by the flame that reaches any receiving surface. For relatively simple geometrical configurations, the view factor can be determined using exact or approximate analytical solutions [13–18]. For problems beyond a certain complexity (e.g. fire scenarios where the front is distorted or even fractal [19]), the MC solution is preferable, although it requires much more effort than finding analytical solution.

The aim of the present paper is to provide a simple, rapid and general means, based on the solid flame model and the Monte Carlo

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doi:10.1016/j.ijthermalsci.2010.09.010