Fire Safety Journal 79 (2016) 57–68

Contents lists available at ScienceDirect

Fire Safety Journal

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

A compartment burning rate algorithm for a zone model

T. Mizukami *,[1], Y. Utiskul [2], J.G. Quintiere [3]

Department of Fire Protection Engineering University of Maryland, College Park, MD, 20742, United States

ARTICLE INFO

Article history:
Received 3 April 2015
Received in revised form
19 November 2015
Accepted 29 November 2015
Available online 8 December 2015

Keywords:
Compartment fire
Experiments
Modeling
Zone model

ABSTRACT

A model is presented that dynamically predicts the mass loss rate of fuel in a compartment as a function of ventilation, thermal feedback, fuel type and scale. Without a loss of generality, a floor-based fuel is considered. The effect of ventilation is included in the model through the ambient oxygen concentration in the ambient surrounding the fuel at the floor. A mixing model associated with the inlet airflow at the vent is developed to determine this oxygen concentration. An extinction criterion for the flame is based on a critical flame temperature for a diffusion flame associated with the ambient conditions surrounding the flame at the floor. The model is executed in BRI2002, a zone model, capable of computing species and thermal conditions in the upper and lower compartment gas layers. Computations show good agreement with small-scale compartment data for heptane pool fires. The results can accurately portray many regimes of burning including extinction, combustion oscillations, reduction in the flaming area, and quasi-steady burning.

1. Introduction

Compartment fires usually commence as a developing, spreading fire that can reach a condition known a *flashover* that drives the available fuel to become involved in decomposition and combustion to its utmost. Flashover raises the thermal conditions and reduces the oxygen in the compartment. The new state of the fire is determined by these conditions in a mechanism that couples the combustion to the conditions. Alternatively, an available amount of fuel can be forced to burn, such as a liquid pool, and the conditions of the compartment will determine the state of burning. In this study, the focus is on the latter, as the developing fire stage is ignored. The state of the fire with the full amount of fuel in the compartment initially ignited is termed the *fully developed fire*.

The fully developed fire is defined as the state where all of the fuel that can get involved is involved. It does not necessarily mean that all of the fuel is burning, since the lack of air would prevent this. Indeed, the fire may go out due to lack of sufficient air supply, or reach a reduced state of burning. As all of the oxygen in the incoming air is depleted, the fire will reach a limiting state known as *ventilation-limited.*

At the ventilation-limited condition, it has been originally reported by Kawagoe from experiments for wood crib [1] that the fuel mass loss rate is proportional to the ventilation parameter in terms of vent area and height, as $A_o\sqrt{H_o}$. However, the divergence of the fuel mass loss rate has been reported by Bullen and Thomas [2], Thomas and Heselden [3] and Tewarson [4]. This illustration is shown in Fig. 1 where the effects of fuel type – wood cribs and small liquid pools – are shown along with the effect of the ventilation parameter. It is shown that the proportionality between the mass loss rate and ventilation factor only holds over a limited range of values of $A_o\sqrt{H_o}$, also it was not an exact constant (6–9 kg/min-m$^{5/2}$) for small pool fires. Then, the influence of external radiation heat flux within the compartment environment is examined. The conventional interpretation is that the wood cribs primarily burn due to internal effects, while the pool fires are fully exposed to the compartment radiation. However, for larger pool fire scales, the flame will block the external radiation heat flux and consequently the burning enhancement would not be as dramatic as shown in Fig. 1 for the small pool fires. In this study, the effects of thermal enhancement, ventilation and scale on burning is modeled, and the contribution ratio of these effect on burning is studied.

Other issue is that Tewarson [4], Takeda and Akita [5], and Kim et al. [6] all note four distinct regimes in compartment burning behavior: (1) extinction, (2) stable laminar burning, (3) *unstable*

* Corresponding author.
E-mail addresses: mizukami-t92ta@nilim.go.jp (T. Mizukami), yutiskul@exponent.com (Y. Utiskul), jimq@umd.edu (J.G. Quintiere).

[1] National Institute of Land and Infrastructure Management, Tachihara 1, Tsukuba, Ibaraki, 305-0802 Japan.

[2] 17000 Science Drive, Suite 200, Bowie, MD20715 USA. Tel.: +301 291 2544; fax: +301 291 2599.

[3] Prof. Emeritus, University of Maryland, 3104G JM Patterson Building, Department of Fire Protection Engineering, College Park, MD 20742. Tel.: +240 472 2016.

http://dx.doi.org/10.1016/j.firesaf.2015.11.005
0379-7112/

Nomenclature

A	Area
c_p	Specific heat
D	Diameter of the fuel pan
f	Mixing Ratio
g	Gravity
H	Compartment Height
Δh_c	Heat of combustion
L	Heat of gasification
$\dot{m}''_F$	Mass loss rate per unit area
$\dot{m}$	Mass flow rate
$\dot{q}''_{External}$	External radiation heat flux per unit area
$\dot{q}''_f$	Flame heat flux
$\dot{q}''_{net}$	Net heat to the fuel surface
r	Stoichiometric oxygen to fuel mass ratio
s	Stoichiometric air to fuel mass ratio
T	Temperature
Y	Mass fraction
ε	Emissivity
ϕ	Equivalence ratio
κ	Extinction-absorption coefficient of the flame
σ	Stefan–Boltzmann coefficient

Subscripts

c	Convection
exp	Experiment
F	Fuel
g	Smoke layer
i	Incident
l	Lower layer
mix	Entraining from upper layer
N	Natural
net	Net
o	Ambient or Opening, free burning
ox	Oxygen
r	Radiation
u	Upper layer
v	Vaporization
w	Wall
∞	Ambient

oscillations, and finally (4) steady burning, including the possibility of *oscillations*. In addition to that, *Ghosting flames*, or unstable flames that drift away from the fuel surface, were observed in the methanol pool fire experiment by Sugawa et al. [7] and Delichatsios et al. [8], in analyzing by Ohmiya et al. [9], noted that not all of the exposed fuel area was involved in burning.

The current study will use the similar experimental database of compartment fire described by Utiskul et al. [10]. The experimental work also has served a basis to validate CFD modeling (using the NIST FDS code) with a prescribed fuel mass loss rate, Hu et al. [11]. In this study, two-slit vents at the top and the bottom of the wall is subjected. Therefore, a dynamic burning algorithm will be described that is styled for use in two-layer zone model (a two-layer control volume approach for the compartment gases), although an early modeling attempt using a single zone (uniform compartment gas property) model had success in describing some features of the experiments. And the model will be capable of addressing these four regimes on burning that have not previously been directly predicted.

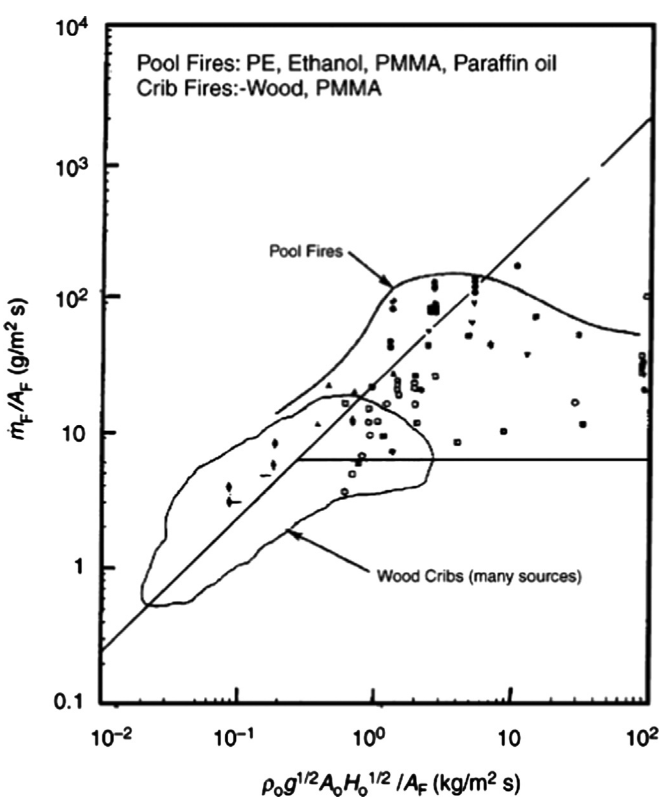

Fig. 1. Fuel mass loss rate versus ventilation parameter in fully developed fires [1].

2. Zone model description

Zone models for application in solving fires in compartments originated in the mid-1970s. Friedman [12] and more recently Olenick and Carpenter [13] describe the current state of zone modeling. Friedman [12] pointed out the deficiencies in modeling the fuel response to vitiated oxygen and thermal feedback.

Fig. 2 illustrates the zone model concept. Zone models describe the fire phenomena in broad strokes of a homogeneous upper and lower layer of room gases penetrated by a fire plume. Models of individual physics and chemistry make up subroutines that are strung together by conservation of mass, species and energy for each of the layers. An orifice model describes the flow through wall vents, and plume entrainment studies give empirical correlations to describe the uptake of lower layer gases into the hotter

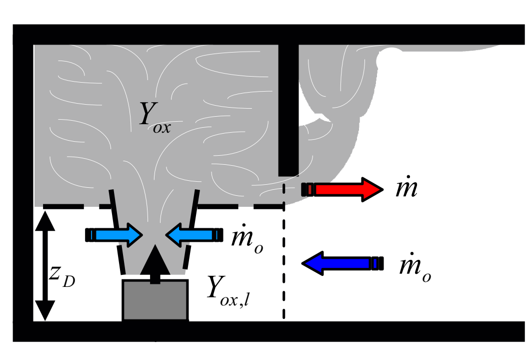

Fig. 2. Basic Zone model for a fire.