APPLICATIONS OF A MODEL TO COMPARE A FLAME SPREAD AND HEAT RELEASE PROPERTIES OF INTERIOR FINISH MATERIALS IN A COMPARTMENT

Woon Hyung. Kim, Ph.D.
Department of Building and Surveying, Glasgow Caledonian University, U.K

James G. Quintiere, Ph.D.
Department of Fire Protection Engineering, University of Maryland, U.S.A

ABSTRACT

Flame spread and heat release properties and incident heat flux of interior materials subject to an ignitor heat flux in a compartment are investigated and compared by using computer model. A corner fire ignition source is maintained for 10 minutes at 100 kw and subsequently increased to 300kw. In executing the model, base-line material properties are selected and one is changed for each run. Also 4 different ignitor heat flux conditions and examined. Results are compared for the 12 different materials tested by the ISO Room Corner Test (9705). The time for total energy release rate to reach 1MW is examined. The parameters considered include flame heat flux and thermal inertia, lateral flame spread parameter, heat of combustion and effective heat of gasfication. The model can show the importance of each property in causing fire growth on interior finish materials in a compartment. The effect of ignitor heat flux and material property effects were demonstrated by using dimensionless parameters a, b and τ_b. Results show that for b greater than about zero, flashover time in the ISO Room-Corner test is principally proportional to ignition time and nothing more.

INTRODUCTION

A flammability measure of interior finish materials using empirical test apparatus has been taken as main criteria by fire regulation in most countries including Korea. The limitation this ranking scale test approach is that the fire growth potential of material in actual fire scenario can be different from the test ranking order. As an alternative , a full-scale test method called ISO 9705 standard room-corner test have been adopted to predict the actual fire performance in terms of energy release rate and time to flash over. A computer model has been developed by Quintiere to simulate fire growth on wall and ceiling materials when subject to a room-corner fire test exposure.[2] The validation and application of this model is explained in his papers.

The purpose of this paper is to explain the effect of the material properties and ignitor heat flux conditions on interior finish performance in the ISO 9705 test using the simulation model. This simulation model has been shown to give good predictability for material representation of the model's physics. Complex property effects and effect of melting and dripping, not included in the model, can not be addressed here. The fire scenario used in the model is based on the ISO 9705 Test. A room 2.4 m x 3.6 m x 2.4 m lined wall and ceiling materials has a doorway opening 0.8m x 2.0 m high. A square burner,0.17 m on a side, located at the room corner, supplies a 100 kw energy release rate to the wall for 10 min, followed by a 300 kw for 10 min. The model address fire spread over wall and ceiling combustible surfaces in a room with a single opening. This include four differential equations for flame spread and burnout fronts in two directions, and integral equation for room temperature, and an algebraic equation for smoke layer temperature[2].

Considering common characteristics of interior finishing material, base line properties and their range of variation were selected. The effect of each property on fire growth is compared by changing 7 parameters.(Table 1.). The model is run to predict the full- scale results from this material data set chosen. In practice, the properties are determined from data obtained using the Cone Calorimeter and LIFT apparatuses. The results are expressed in terms of flashover time that corresponds to an energy release rate for the ISO room of 1MW. The model computes this as $\dot{Q}(t) = \dot{Q}_{ig} + \dot{Q}'' A_p(t)$ (1)

where $\dot{Q}_{ig}$ is the ignition burner energy release rate, $\dot{Q}''(t)$ is the energy release rate per unit area of the material and A_p is the pyrolysis area. The pyrolysis area is computed from the flame and burn-out fronts as shown in Fig.1. Also considered is the ignitor flame heat flux that was taken as 40 kw/m^2, 50 kw/m^2, 60 kw/m^2, 70 kw/m^2 in the model. The heat flux for flame spread was maintained at 30 kw/m^2. Material properties can be assumed to the independently affect flashover time. These are as follows :

1. Ignition Temperature, T_{ig}
2. Thermal Inertia, $k\rho c$
3. Lateral Flame Spread Parameter, Φ
4. Minimum Temperature for Lateral Spread, $T_{s,min}$
5. Heat of Combustion, ΔH_c
6. Effective Heat of Gasfication, L
7. Total Energy per unit Area, Q''

Table 1. Input Parameters

T_{ig} (°C)	$k\rho c$ (kw/m^{2}K)^{2}s	Φ (kw^2/m^3)	$T_{s,min}$ (°C)	ΔH_c (KJ/g)	L (KJ/g)	Q'' (KJ/m^2)	Remark
				4		1,000	
	0.05	0.5		6	0.5	3,000	
200	0.1	1	20	8	1	5,000	
300	0.3	2	100	10	2	7,000	
400	0.5	4	150	15	4	10,000	Base-Line
500	0.8	6	250	25	6	30,000	
600	1	10	350	35	10	50,000	
	1.2	20	450			70,000	
	1.5					100,000	
	1.8						
	2.0						

RESULTS

1.Material properties effect at different burner heat flux levels

The room-corner model was run with changing input parameters one at a time with the others fixed at the base-line. A set of results over the property range was found for each ignitor heat flux selected. The results are as shown in Fig.1-3.

(1) Effect of Ignition Temperature, T_{ig}

The range of interior material ignition temperature varies from 250°C to 450°C for piloted ignition, with values above 500°C for auto- ignition. In the model, T_{ig} was changed between 200°C and 600°C. Time to ignition is proportional to the square of ignition temperature rise above ambient, and it is inversely related to the flame spread speed.

Hence we might expect the time to flashover to increase with the ignition temperature. The computed results for ISO room corner test are shown in Fig.1

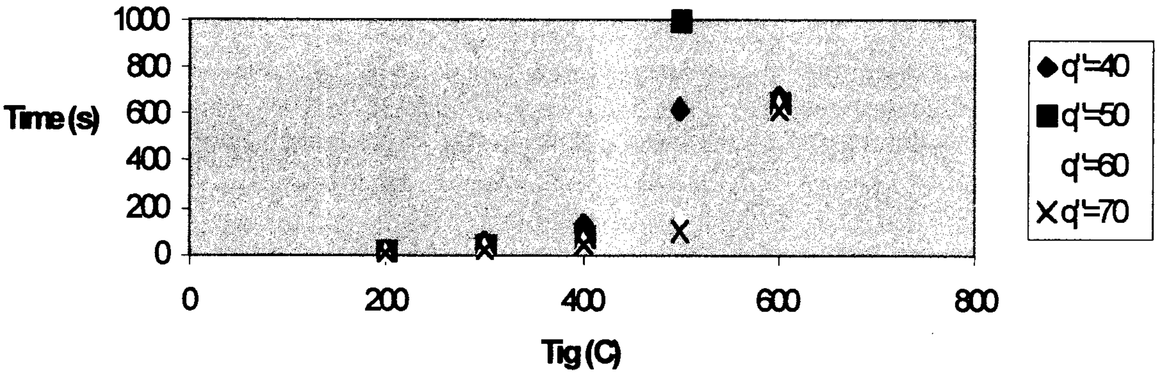

Fig.1 The effect of ignition temperature

At 500°C, no flashover was reached at a flame heat flux of 50 kw/m^2. But at 624 seconds at 40 kw/m^2 flashover occurred. Though the latter has a lower heat flux, the energy release rate of this case increases rapidly about 600 seconds. Flashover time is affected by the ignitor burner change from 100 kw to 300 kw after 600 seconds.

The ignition time of heat flux with 50 kw/m^2 is faster than that of 40 kw/m^2 and burn-out early before 200 s. As shown in Fig.2. the ignitor burner was changed to 300 kw at 600 seconds, then burns again until 1200 seconds at which burner is shut off. These apparent anomalies in the effect of T_{ig} and ignitor heat flux are due to the complex interaction of ignition, spread rate, burn-out and energy rate. Such effects do not necessarily follow simple correlation when many parameters are involved. This is the advantage of using the simulation model.

(2) kρc

In the thermal inertia property, specific heat (c) does not very much among solid materials and thermal conductivity (k) is proportional to density(ρ). So thermal inertia is roughly proportional to the square of density. A material with high thermal inertia takes longer to reach ignition compared to that of a lower one and therefore higher thermal inertia materials needs more time to reach flashover.

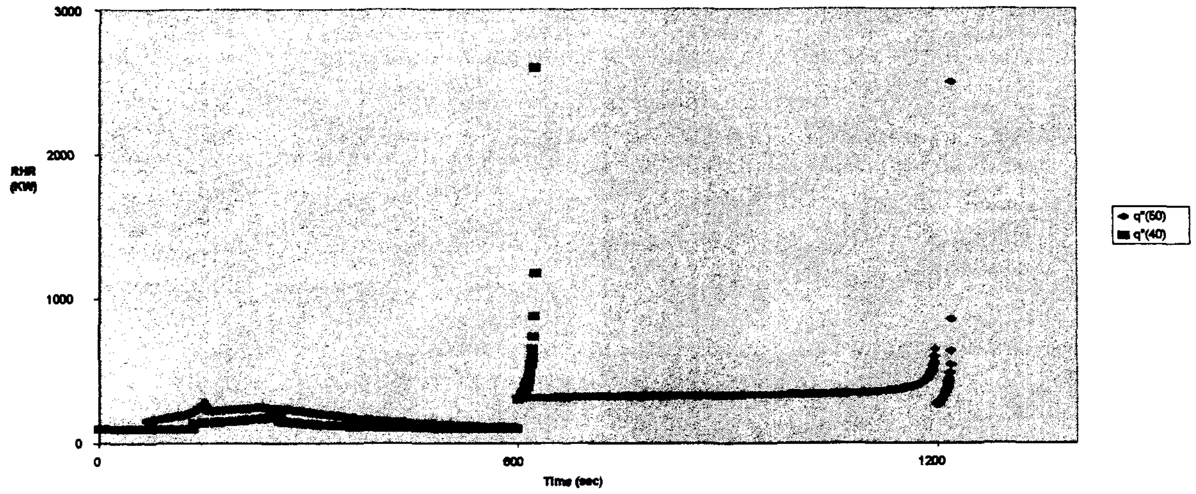

Fig.2 Energy Release Rate (at $T_{ig} = 500^{o}C$)

The simulation results showing the effect of flashover time as a function of thermal inertia is shown in Fig.3. Again, here is a similar anomaly in ignitor heat flux effect like we saw in Fig.2. If the value of kρc is below 0.6, the flashover time is more sensitive than that of above 1.2. When the value lies between 0.8 and 1.0, the time to flashover increased rapidly with increased thermal inertia and does not vary monotonically with ignitor heat flux.

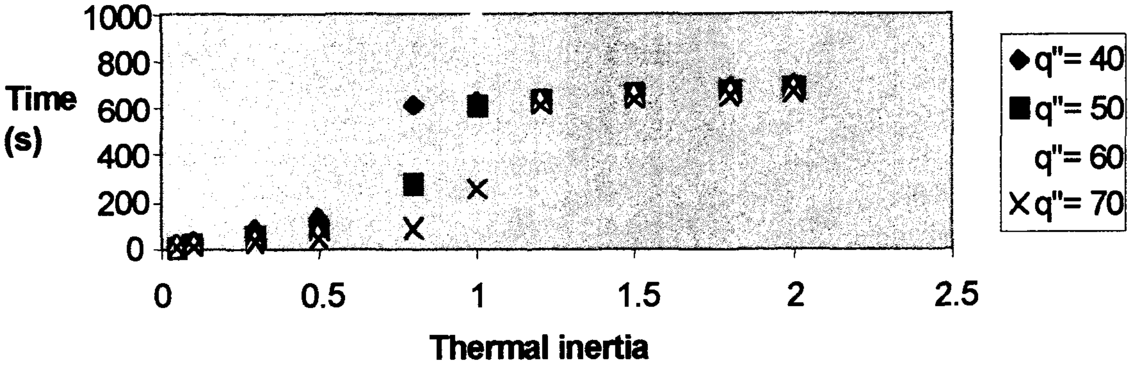

Fig. 3. The effect of thermal inertia

(3) ΔHc and L

It can be shown [1] (or see Eq. (9)) that If the burn-out time of the material is a much bigger value than time to ignition, then t_{ig} / t_b is very small and the time to flashover is related to the ratio, ΔHc / L. Theory suggests that under this condition of large t_b, there is a minimum ratio of heat of combustion per heat of gasfication express the energy release per energy required to allow flame spread. This ratio can be calculated in the case of different incident heat flux condition. In the case of wood the effective heat of combustion in flaming condition has 13 kj/g and 6 kj/g can be taken as a representative heat of gasfication. This can be enough to allow flame spread. Most liquids have L = 0.3 to 1.5 kj/g, and solids have L= 2 to 5 kj/g for their effective heats of gasfication.

(4) Total energy per unit area

For the property, total energy per unit area, the computed time to flashover decreases rapidly from over 600 s to less than100 s when the total energy per unit area has a value between 5,000 kj/g (e.g. PVC Covered gypsum board, FR Particle board - [4]) and 7,000 kj/g (e.g. Paper covered gypsum board, Melamine faced high density non-combustible board-[5]). If the value above 10,000 kj/g, each heat flux case has the same flashover time

2.An empirical correlation

An analytical expression that gives the dimensionless energy release rate of the material as a function of time during upward flame spread follows from Cleary and Quintiere [1]

$$\dot{Q}/\dot{Q}_o = [\,(1+a)^2 e^{a(\tau-1)}-1\,]\,/\,a \qquad \text{for } 1 \le \tau \le \tau_b + 1 \qquad (2)$$

$$\dot{Q}/\dot{Q}_o = [\,(1+a)^2 (e^{a\tau b} - 1)\,/\,a\,]\, e^{\,b(\tau-1-\tau b)} \qquad \text{for } \tau \ge \tau_b + 1 \qquad (3)$$

where $\dot{Q}$ is the energy release rate of the material, $\dot{Q}_o$ is the energy release rate of the burner, τ is dimensionless time, t / t_{ig} , τ_b is dimensionless burnout time, t_b / t_{ig} .

A single dimensionless parameters a, b are given as

$$a = k_f \dot{Q}'' - 1 \qquad (4)$$

k_f is a flame length coefficient, 0.01 m^2 / kw (by Quintiere) [1]

$\dot{Q}''$ is the energy release rate per unit area,

where $$\dot{Q}'' = \Delta H_c / L\,(\,\dot{q}_f'' - \sigma T_{ig}^4 + \sigma T^4\,), \qquad (5)$$

$\dot{q}_f''$ = incident flame heat flux over the pyrolysis area, (or the ignitor flux)

T_{ig} = ignition temperature

ΔH_c = Heat of combustion

L = Effective heat of gasfication

σ = Stefan-Boltzmann constant

σT_{ig}^4 = re- radiation heat flux loss

σT^4 = incident heat flux from the compartment.

Also $$\dot{q}_{net}'' = \dot{q}_f'' - \sigma T_{ig}^4 \qquad (6)$$

$$b = a - 1 / \tau_b \qquad (7)$$

$$t_b = Q'' / \dot{Q}'' \qquad (8)$$

$$b = 0.01\,(\Delta H_c / L)\,\dot{q}_{net}'' - 1 - t_{ig} / t_b . \qquad (9)$$

The ignition time is given as

$$t_{ig} = \pi/4\ k\rho c\,(T_{ig} - T_s / \dot{q}_f'')^2 \qquad (10)$$

where T_{ig} is the ignition temperature, $k\rho c$ is the thermal inertia, T_s is the surface temperature and $\dot{q}_f''$ is the radiant heat flux above the flame region controlling spread assumed 30 kw/m^2 recommended by Quintiere [2].

Parameter b depends on the material controlling spread properties and the flame heat flux conditions. The flame spread accelerates to reach flashover for $b > 0$ and decays for $b < 0$ in theory. The dimensionless parameter b in Fig.4 has empirically been found to correlate with fire growth flashover time for 24 materials tested in the S and E ISO room-corner series [4,5].Very similar results are found with the simulation of this paper applying 60 kw/m^2 heat flux in Fig.5.

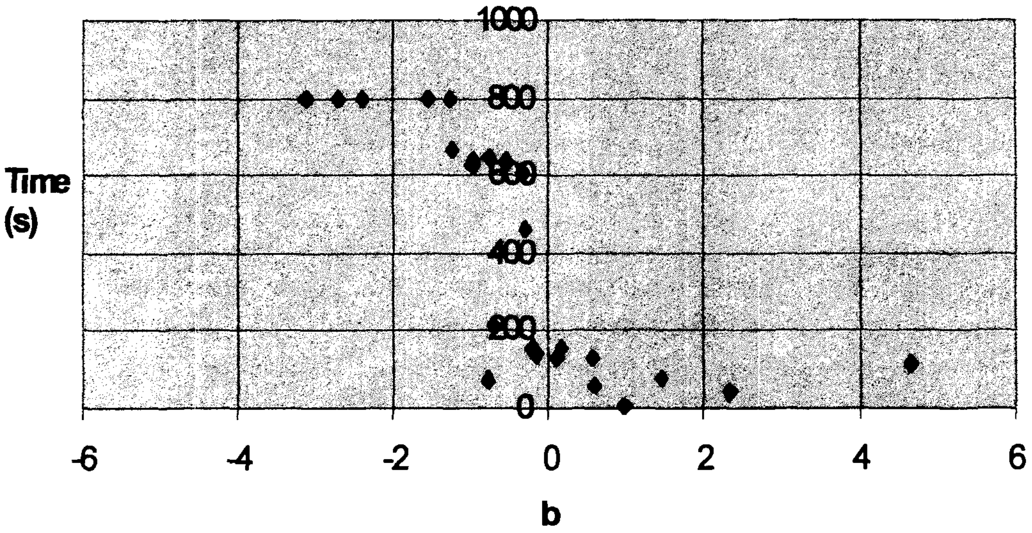

Figure 4. Time to flashover (EUREFIC Test)

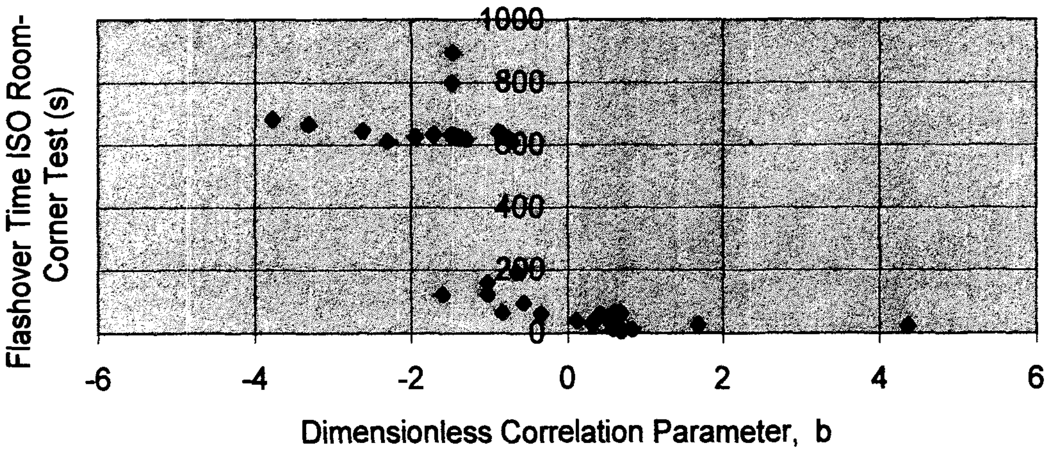

Figure 5. Time to flashover (Calculation.)

In the case of $\dot{q}_f''=40$ kw/m^2, the time to flashover strongly depends on the time to ignition of material when $b \geq -0.7$. If $b \geq -0.7$ flashover generally occurred within 200 s with 100 kw burner exposure, and if $b < -0.7$, this flashover were likely occurred after 600 s with the 300 kw burner exposure. This is the almost same phenomenon in all different ignition sources of 50, 60, and 70 kw/m^2 heat fluxes. From Eq.(3) the basic of the empirical correlation in Fig.5 and 6 can be explained. Flashover occurs at a given energy release rate for fixed room conditions. Therefore we see that the dimensionless flashover time, $\tau = t_{fo} / t_{ig}$, can be expressed as t_{fo} / t_{ig} = function (a, b, τ_b).

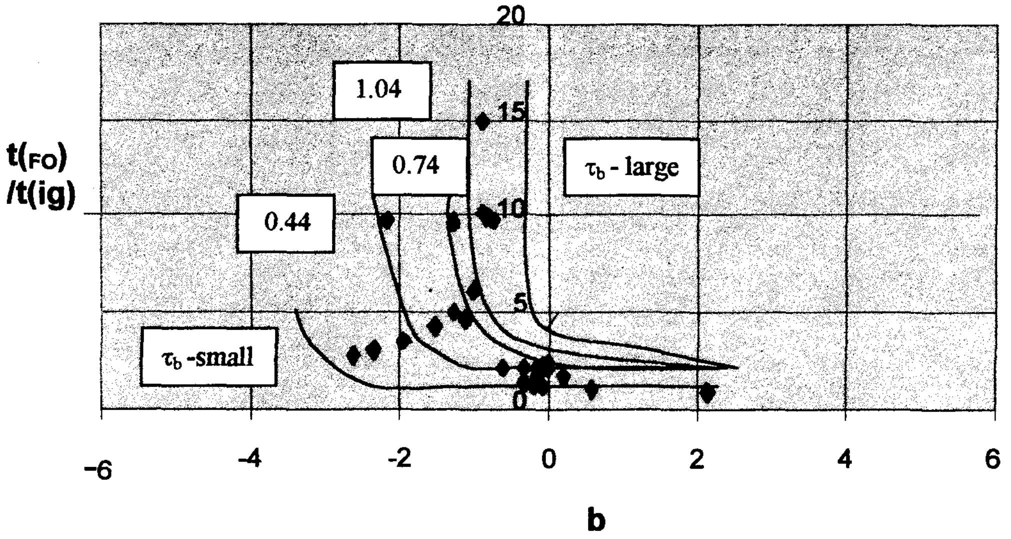

Figure 6. Dimensionless flashover time

By considering only the exponent we expect a flashover energy release rate to occur roughly $b(\tau - 1 - \tau_b) = \text{constant}$. A plot of t_{fo} / t_{ig} is hyperbolic in b and moves to the left as τ_b decreases. The simulation runs (for $\dot{q}_f''=40\ \text{KW/m}^2$) are shown in Fig.6. When we examined the τ_b values we find the trend suggested by the competitions. As $\dot{q}''$ increases, these results shift to the light. For $b>-0.7$ t_{fo} / t_{ig} is relatively insensitive to b and τ_b and varies from about 1.7 to 2.2. This means in this range, flashover time is only proportional to ignition time. It does not depend on energy release rate and other material properties. So for materials that tend to flashover given the 100 kw exposure, time to ignite is the key indicator if hazard.

CONCULUSION

This paper examined the effect of changes in specific material properties using theoretical model applied to the ISO 9705 room- corner test scenario. The results show how the time to flashover depends on each property, and on the ignitor energy output of 100KW for 10 minutes followed by 300KW for another 10 minutes. The effect of ignitor heat flux was also simulated. The theoretical results, taken for all of the property runs, display a similar character to empirical results which show that flashover time depend principally on a single dimension parameter b. However for b greater than about zero, flashover time is theoretically and empirically found to principally depend on ignition time.

NOTATION

A	area
b	parameter defined in Eq. (9)
c	specific heat
k	thermal conductivity k_f empirical constant, Eq. (4)
q	heat
Q	energy release
t	time
T	temperature
ρ	density
τ	dummy variable for time, Eq. (2)
ΔH_c	heat of combustion

Subscripts

B	burn-out
F	flame
Ig	ignitor, ignition
min	minimum
p	pyrolysis
s	surface

Superscripts

$(^\bullet)$	per unit time
$(\,)'$	per unit width
$(\,)''$	per unit area

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