Estimation of Thermal Radiation from Large Pool Fires

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ABSTRACT

The one mesh model[1], which has been developing by one of authors recently, is employed to estimate thermal radiation from large pool fires having diameters over 10m. The predicted results are compared with the experimental results.

1.INTRODUCTION

Thermal radiation plays a very important role in pool fires, because the burning rate of large pool fires is greatly influenced by radiative heat transfer. The problem of thermal radiation hazards also depends on the characteristics of radiative heat transfer. In an attempt to estimate thermal radiation from pool fires, the authors have been devising a new and simple simulation model which is called the one mesh model. The analytical results of the one mesh model were compared with the experimental results and values in the literatures[2-7].

2.EXPERIMENT

Kerosene pool fire tests were conducted under a quiescent atmosphere of a large indoor test space of FRI(24mx24m,20mhigh). The size of pool fires were 1m round and 2.7m square tanks. Radiative heat from flames was measured with wide angle radiometer located at a distance 5D (D is the tank diameter) from the center of the tank. Kerosene was fed above water which was filled into the tank before experiment. Burning rate was measured by electrical float level meter. These experimental setup is shown in Fig.1.

3.ANALYTICAL MODEL

3.1 FLAME MODEL FOR POOL FIRES AND HEAT BALANCE EQUATION A simple analytical model which is called one mesh model is introduced to estimate thermal radiation from large pool fires. The one mesh model has been recently developing by one of the authors. The flame shape of pool fires is assumed to be a cylindrical one for simplicity as shown in Fig.2. Properties such as temperature, T_f and absorption coefficient, k are considered to be uniform within the flame model. Heat generation due to the combustion of fuel is assumed to take place within the flame model. Therefore, the heat balance equation for this flame model are made up of heat generated by combustion of fuel, $Q_{f,i}$, heat carried with entrained air, $Q_{a,i}$, radiative heat from the surrounding air, $Q_{r,i}$, heat of fuel vaporization, $Q_{f,o}$, heat carried away from the top of the flame by flown, $Q_{g,o}$ and heat loss by radiation to the surroundings, $Q_{r,o}$. These heat terms are shown in Fig.2 with arrow. Then the heat balance equation is:

$$Q_{f,i}+Q_{a,i}+Q_{r,i}=Q_{f,o}+Q_{g,o}+Q_{r,o} \qquad (1)$$

where $Q_{f,i}$ is:

$$Q_{f,i}=\eta m_f \Delta H_c \qquad (2)$$

where η is the combustion efficiency, m_f is the fuel burning rate(kg/s), ΔH_c is the heat of combustion(Ws/kg).

$Q_{a,i}$ is:

$$Q_{a,i}=m_a c_{pa} T_a \qquad (3)$$

where m_a is the mass velocity of entrained air(kg/s), c_{pa} is the specific heat of air(Ws/(kgK)), T_a is air temperature(K).

$Q_{f,o}$ is:

$$Q_{f,o}=m_f(\Delta H_f+(T_b-T_a)c_f) \qquad (4)$$

where ΔH_f is the heat of vaporization(Ws/kg), T_b is the boiling point of fuel(K), c_f is the specific heat of fuel(Ws/(kgK)).

$Q_{g,o}$ is:

$$Q_{g,o}=(m_a+m_f)c_{pg}T_m \qquad (5)$$

where c_{pg} is the specific heat of combustion gas(Ws/(kgK)), T_m is mean temperature of of the flame model.

Other terms of $Q_{r,o}$ and $Q_{r,i}$ are described in the following section.

3.2 RADIATION MODEL FOR POOL FIRES Total heat loss by radiation to the surroundings of the flame model, $Q_{r,o}$ is:

$$Q_{r,o}=4(1-\alpha_s)\sigma k_m T_m^4 V \qquad (6)$$

where σ is Stefan-Boltzmann constant(5.67×10^{-8}W/(m^{2}K^4)), V is flame volume and α_s is a self-absorption factor. Approximate value of α_s for various shapes of gas mass can be calculated easily using the following equation cosisting of k_m, V and a surface area of the flame model, S.

$$\alpha_s=1-(1-\exp(-ck_mL))/(k_mL) \qquad (7)$$

where c is a factor, which is given in the reference[8], for various gas shapes. L is the mean beam path length and can be expressed as:

$$L=4V/S \qquad (8)$$

Radiation from the entire flame model is assumed to be emitted uniformly to the surroundings from the point which located on the center line of flame of height D above the tank. Therefore the radiative energy per unit area q_x at the distance L=5D is:

$$q_x=(1-\alpha_s)Q_{r,o}/(4\pi(L^2+D^2)) \qquad (9)$$

Measured and calculated irradiance are compared at a dimensionless distance of 5(=L/D) in this paper.

$Q_{r,i}$ is radiative heat from the surrounding air:

$$Q_{r,i}=\sigma\varepsilon_a S T_a^4 \qquad (10)$$

ε_a is an emissivity of air and set to unity.

$Q_{f,o}$ of eq.(4) is also expressed as:

$$Q_{f,o}=\sigma\varepsilon_{base}A_sT_{base}^4+A_sh_s(T_m-T_b) \quad (11)$$

where ε_{base} is an emissivity at the bottom of the flame model:

$$\varepsilon_{base}=1-\exp(-0.814*0.85kD) \quad (12)$$

T_{base} are the temperature at the flame model bottom and h_s is a convective heat transfer coefficient between flame and fuel surface.

3.3 ANALYTICAL MODEL FOR AIR ENTRAINMENT AND FLAME HEIGHT To obtain $Q_{r,o}$, $Q_{r,i}$ and m_a, the following mathematical model is introduced to the one mesh model. According to Fang[9] and Ndubizu[10], the rate of air entrainment into the flame model can be obtained if we know the flame height above the tank H_f, Froude number Fr, heat generation in the fire and properties of the ambient atmosphere. The flame height H_f is given by

$$H_f=y_0 1.49\theta_1^{1/5}Z^{2/5} \quad (13)$$

where y_0 is radius of the tank, θ_1 is given by

$$\theta_1=\omega(\omega/\rho_o'+\gamma/X_{o2})^2/\alpha_f^4/(1-\omega) \quad (14)$$

where γ is the stoichiometric oxygen/fuel ratio, X_{o2} is the oxygen mass fraction in the air, α_f is the entrainment coefficient, ω is given by

$$\omega=M/M_a/(1+(\Delta H_c X_{o2})/(\gamma c_{pa}T_a)) \quad (15)$$

where M is average molecular weight of species in the fire, M_a is molecular weight of environmental air. Z is the modified Froude number and given by

$$Z=\rho_o'Fr^{1/2} \quad (16)$$

where Fr is the Froude number and given by

$$Fr=(m_f/\rho_v/A_s)^2/(gy_0) \quad (17)$$

where ρ_v is the density of vapor , A_s is the area of fuel surface, g is acceleration due to gravity. ρ_o' is the normalized density at the fuel surface and is given by

$$\rho_o'=M_fT_a/(29T_s) \quad (18)$$

where M_f is the molecular weight of fuel, T_s is fuel surface temperature. Finally, the rate of air entrainment into the flame model m_f is

$$m_a=m_f\rho_o'^{-1}\omega((0.4\alpha_fX_iH_f/y_0+1)^{5/2}-1) \quad (19)$$

where X_i is

$$X_i=((1-\omega)/(\alpha_f\omega Fr))^{1/5} \quad (20)$$

3.4 ANALYSIS PROCEDURE The calculation procedure of the one mesh model is shown in Fig.3. If a tank diameter D, absorption coefficient k and fuel properties are given, m_f, m_a, H_f and q_x can be obtained usually after several times of iteration.

4.RESULTS AND DISCUSSION

The one mesh model has been tested on kerosene pool fires of tanks with diameters of 0.1m to 100m. The predicted and measured fuel burning rate are shown in Fig.4. The solid line represents the calculated results by the one mesh model.The one mesh model does well in predicting the burning rate of large diameter fires (D > 2m). The predicted and measured irradiance at L/D=5 are shown in Fig.5. The solid and broken lines represent the calculated results by the one mesh model. The one mesh model does well in predicting the burning rate of large diameter fires (D < 2m). Unfortunately, the one mesh model can not predict large diameter fires (D > 3m) at present. This is because the combustion model which can predict the efficiency of combustion has not been completed. However broken lines in Fig.5 express the effect of the efficiency of combustion on irradiance and we can notice the efficiency of combustion may decreases rapidly when tank diameter exceeds 10m.

5.CONCLUSION

A simple analytical model which is called the one mesh model has been developing to predict the characteristics of pool fires. The predicted and measured fuel burning rate and irradiance of kerosene pool fires show good agreement but further work to make the combustion model which can predict the efficiency of combustion is needed.

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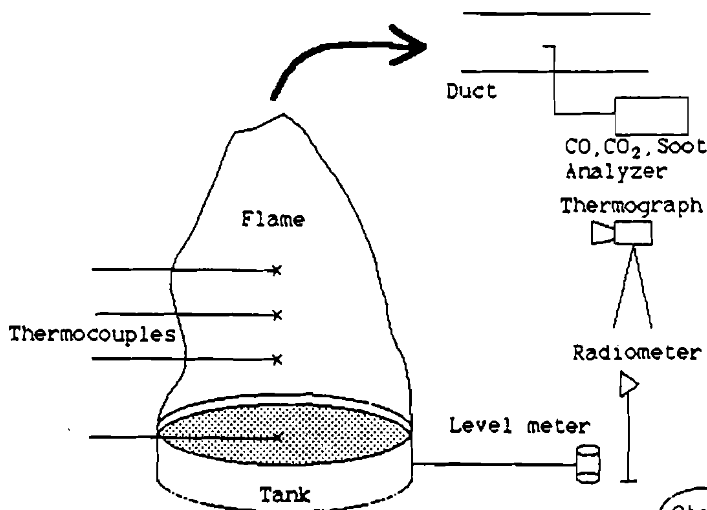

Fig.1 Schematic of experimental set up

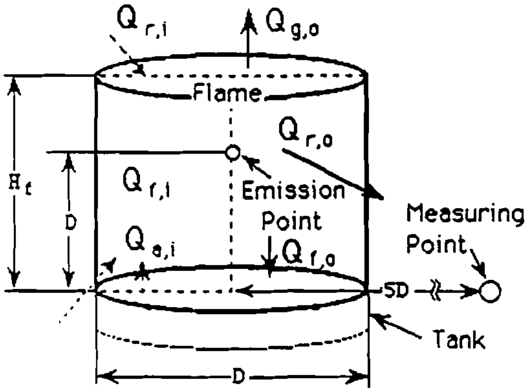

Fig.2 Flame model of the one mesh model

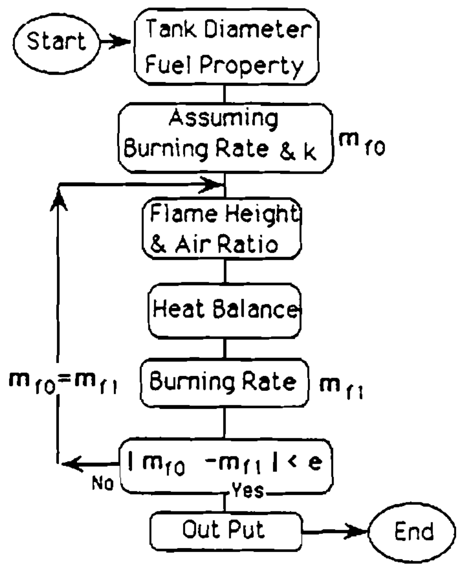

Fig.3 Computational procedure

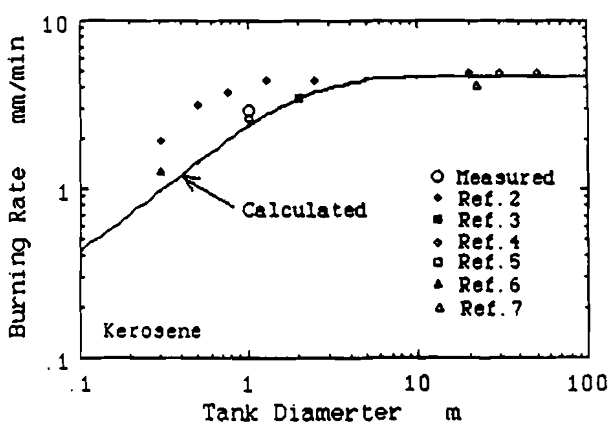

Fig.4 Burning rate

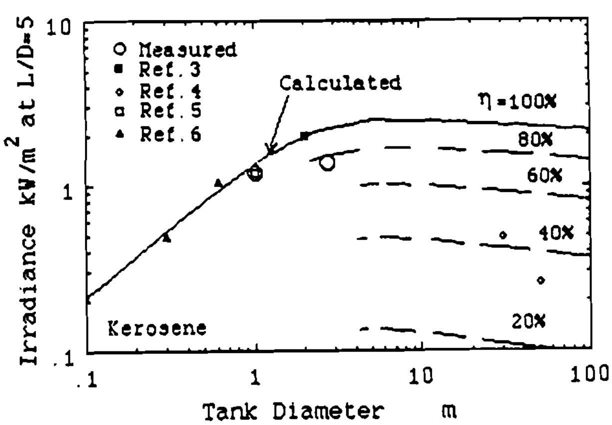

Fig.5 Irradiance