The Modeling of Pulsating Fires

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The authors present scaling relationships for modeling pulsating fires. Data gathered from various sizes of pulsating fires compared favorably with the predicted relationships between fire diameter and pulsation frequency.

A RHYTHMIC pulsation of the flames over burning fuel is a frequently observed phenomenon which characterizes certain types of fires. Pulsations are most likely to appear over burning areas that are circular, or nearly circular, in shape. They are most pronounced in quiet, stable air. The pulsation cycle starts with an expansion of the flames near the base of the fire and is followed by a sudden collapse of these flames toward the center of the fire. A flame bulge then travels upward to the flame tip in an even, wavelike motion. Expansion of the lower part of the flames starts the cycle again.

The scaling laws for modeling pulsating fires are part of a larger group of laws that apply to the behavior phenomena of both moving and stationary fires. Tests and verification of the general group of scaling laws must await a comprehensive program of modeling which will involve difficult experimental work. However, the pulsating fire can be readily produced over a wide range of sizes in the laboratory, and thus offers a relatively simple way to test some of the scaling laws and to gain some indication of the validity of others. This paper presents the essential scaling relationships and an account of the associated experimental work in a study of the modeling of pulsating fires.

DEVELOPMENT OF SCALING LAWS

Owing to the complexity of fluid flow in many convection processes, dimensional analysis seems to offer one of the best methods for developing the scaling laws needed to model the convection phenomena of fire behavior. The pulsating fire is an example of a physically complex phenome-
non for which the dimensional analysis is relatively simple and straightforward. The details of the dimensional analysis will not be given, but the procedures and basic assumptions are similar to those described by Byram for other characteristics of stationary fires.

It is assumed that a circular perimeter of diameter $D$ encloses the burning area over which the unit area burning rate (the rate of convective heat output per unit area) is constant and equal to a steady-state value $I_a$. The atmosphere is assumed to be an isothermal, incompressible fluid with the same coefficient of thermal expansion as the actual atmosphere and also with the same specific heat $c_p$ and density $\rho$. If viscous forces are disregarded, the dimensional analysis gives two dimensionless groups, or variables, which characterize the pulsation phenomenon. These are

$$\pi_1 = t (g / D)^{1/2}$$

and

$$\pi_2 = \frac{I_a}{(gD)^{1/2} \rho c_p T}$$

where $t$ is the pulsation period, $g$ the acceleration due to gravity, and $T$ the temperature of the ambient air. The term $\pi_1$ can be regarded as a dimensionless time; $\pi_2$ is a key dimensionless variable, which may be defined as a buoyancy number. In experimental work, the pulsation frequency $1/t$ is sometimes a more convenient variable to use than $t$. The corresponding dimensionless frequency, or frequency number is

$$\pi_1' = 1 / \pi_1 = (1 / t) (D / g)^{1/2}.$$  

For complete modeling, the necessary scaling laws are obtained by letting each $\pi$ have the same value in the model and full-scale fires (or in a wide range of model sizes). If $\pi_1$ and $\pi_2$ have the same value in the model and full-scale fires, it immediately follows that

$$\frac{t_m}{t_f} = \left( \frac{D_m}{D_f} \right)^{1/2} \quad (1)$$

and

$$\frac{(I_a)_m}{(I_a)_f} = \left( \frac{D_m}{D_f} \right)^{1/2}, \quad (2)$$

which are the required scaling laws. The quantities $g$, $\rho$, $c_p$, and $T$ have been treated as constants. The subscripts $m$ and $f$ denote model and full-scale fires, respectively. The full-scale fire and its model are geometrically similar because, in either $\pi_1$ or $\pi_2$, the variable $D$ may be treated as any typical length in the system. Thus, the ratio of any two lengths in the