Pressures developed by fire

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TECHNICAL NOTE

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PREPARED FOR In answer to an inquiry

SUBJECT PRESSURES DEVELOPED BY FIRE

Consideration has been given, following an inquiry, to the pressures which might be developed within a building as a result of the development of a fire. The question which was raised, specifically, was in relation to the possibility that portions of the interior cladding might be dislodged or displaced as a result of pressures generated by fire.

The slight pressure differentials which will be established between outside atmosphere and the interior of a building involved in a fire will have two distinct components. The first will be related to the differential of the mean temperature of the enclosure with time and hence will have most significance during the growth and decay periods of the fire. At all heights it will be positive (i. e., interior pressure exceeds exterior) during the growth period and negative during the decay period.

The second component will be related to the absolute value of temperature and not to variations, and will be of greatest significance during periods of peak temperature. Both its sign and value will be dependent on height and also on the height and relative areas of vents. The upper limiting value of this second component is readily calculable. Thus the maximum positive pressure difference between the highest point in a burning enclosure of height h and the exterior atmosphere at that height will occur when the venting areas communicating with the atmosphere are at the lowest possible level. The pressure difference will be given by

$$\delta p = h(\rho_o - \rho_\theta)g = hg\rho_o \Theta / T'$$

where

ρ_o = atmospheric density
ρ_θ = gas density within enclosure
T' = absolute temperature of gases
$\Theta = T' - T_o$ where T_o = atmospheric temperature

If δp is to be expressed in inches, water gauge h_w, then provided the value of h is now expressed in inches and a value of 0.0012gm/cc is assumed for the density of atmospheric air, the expression for h_w reduces to

$$h_w = 0.0012h\,\Theta / T'$$

Numerous measurements at fires, including those at the St. Lawrence Burns, show that mean gas temperatures in typical building fires are lower than 1000°C. If a value of 1000°C is assigned to Θ then it can be said that for a fire in an 8-ft 6-in. high story of a structure, the maximum positive pressure at the ceiling resulting from the mechanism under discussion will not exceed 0.1 in. water gauge unless unusual fuels leading to temperatures much higher than those just quoted are involved. In general, pressures will be lower than this value by a factor of at least 2, partly because mean temperatures will be lower and partly because the vertical distribution of vents will give a neutral pressure axis about half way between floor and ceiling heights. Where very high enclosures are considered, of course, pressure differentials could be proportionately greater.

The above results can be considered directly applicable to the case of a suspended ceiling, where the ceiling constitutes a good seal and the space above it is heavily vented to the exterior. Where the aggregate leakage area through the ceiling greatly exceeds the vent area the pressure differential will, of course, tend to zero.

The first component of pressure differential discussed at the beginning of this note is not so readily amenable to calculation, the principal impediment being a prediction of the rate at which the gas temperature within the enclosure will increase during the primary stage of the growth of the fire. Where, say, gasoline vapours are involved in a fire, the growth can be explosive, and in comparison with the value previously derived the pressure differential could be very high. Such gas explosions can be quite destructive, often shifting or damaging walls and floors. They can and often do occur without a following fire.

A similar but much less severe effect can take place when more common fuels are involved in building fires. The necessary initial conditions are poor ventilation giving rise to a large volume of gas which includes a substantial proportion of volatiles distilled from the associated combustibles. A sudden change in ventilation conditions can then introduce sufficient air to bring about rapid combustion. In its extreme form occurring under unusual fire conditions, a mild explosion leading to substantial pressure rise could occur Much more common is the case in which the compartment is only partially filled with a mixture of volatiles and inert products of combustion and a much milder and much less rapid development of pressure can be expected.

For the majority of cases where a more normal development of fire is involved a prediction of the pressure differential can be obtained by postulating the rate of temperature rise of the gases within the enclosure involved. In comparison with the absolute values of the pressures involved the pressure differentials may be neglected so that the velocity v of the gas flow through a crackage or vent area A will be governed by the conservation equation

$$Av = \frac{dV}{dt} = \frac{V_o}{T_o}\frac{dT}{dt}$$

where V is the volume of the gases originally contained within the enclosure

T is temperature
T_o is the ambient temperature
V_o is the volume of the enclosure.

But by Bernoulli's equation, neglecting flow coefficients, the resulting pressure differential will be

$$\delta p = \rho v^2/2$$

where ρ is the density of the gases.

Substituting for v and expressing δp in terms of water gauge pressure

$$h_w = \frac{\rho}{2\rho_w g}\left(\frac{V_o}{AT_o}\frac{dT}{dt}\right)^2$$

where ρ_w is the density of water, and g is the acceleration due to gravity.

Consider a volume 40 by 25 by 8 ft, a total vent or crackage area of only 2 in. by 4 ft and a temperature rise of 20°C/minute which may be taken as a reasonable rate of rise of mean temperature in the compartment under such restricted ventilation conditions. The greatest pressure will occur with the highest value of ρ say 0.0012gm/cc (the density at ambient temperature); substituting these values gives a result of 0.04 in. water gauge.

With much greater ventilation conditions, the rate of mean temperature rise might well be as high as 100°C per minute even with conventional fuels. But the higher vent area required to establish this more rapid rate of temperature rise would also provide correspondingly greater pressure relief.

In an exploratory series of experiments carried out by the Fire Section in an enclosure some 12 by 6 by 9 ft, pressures were found to be substantially lower than this value. Precise measurements were, in fact, not possible because of ambient pressure variations of the same order.