Course Name: Theory of Fire Propagation (Fire Dynamics)

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Week – 12

Lecture – 04

Module 9 – Fire safety aspects

Fire detectors:

Fire can be detected by sensing the presence of smoke, heat, flames and product gases.

Heat detectors – These are often used in smaller compartments where fire can grow at a faster rate. The response time for heat detectors is comparatively higher. Heat detectors work on various mechanisms. Primarily, a part of it or a working substance present in the heat detector responds to the incident heat flux. In a bimetallic-type heat detector, two metals having quite different coefficients of thermal expansion are used. The relatively larger expansion undergone by one of the metals causes a deflection in the mechanism. A heat detector with a fusible element uses an eutectic alloy that melts rapidly when heated to a given temperature.

Smoke detectors – In ionization smoke detectors, a special radioactive material is used to ionize the air flowing through the detector. Ionization is affected by the presence of smoke. When pure air is ionized, a certain quantity of current flows through the detector. This amount decreases when smoke enters the detector. When a certain concentration of smoke enters the ionization detector, the detector triggers an alarm. In a photoelectric smoke detector, a light source and receiver are used. The light source is directed towards the receiver. In pure air medium, a certain intensity of light is received. When smoke is present in the line of sight, the intensity of light received by the receiver reduces. This is called the light obscuration principle. When the receiver receives light below a certain intensity, the alarm is triggered.

In another type of photoelectric smoke detector, the light source and receiver are not kept aligned as in the light obscuration principle. Light enters the receiver when smoke particles scatter it. When the receiver receives a certain amount of light, the alarm is triggered. Photoelectric detectors are more suitable for grey smoke, and ionization detectors are more suitable for dark smoke. In places with high humidity, photoelectric detectors are suitable.

Other special types of smoke detectors are projected beam detectors (work on the light obscuration principle) and cloud chamber detectors. The location, capacity, and installation of these detectors are carefully done as per standards.

Flame detectors – These detectors detect the ultraviolet (UV) and/or infrared (IR) emissions from fire. These have fast response and usually used in industries and fuel handling facilities where the fire hazard is high. Both UV and IR detectors should be positioned so as to view the flame. Therefore, these are kept focussed towards the hazardous areas. IR detector should not be allowed to see sunlight.

Gas detectors – These detectors detect carbon monoxide (CO) and carbon dioxide (CO_2). CO detectors are commonly used in residential apartments nowadays. Apart from these, pressure detector that detects excess pressure is also used.

Minimum heat release for activating fire detector:

Usually the heat detector is mounted on the ceiling. Considering a fixed temperature heat detector having a temperature rating of T_L, the minimum heat from fire that will enable heat detection can be calculated using Alpert correlations available for ceiling jets:

$$\dot{Q}_{min} = \left[\frac{T_L - T_\infty}{16.9}\right]^{\frac{3}{2}} H^{\frac{5}{2}} \quad for\, r/H \leq 0.18$$

$$\dot{Q}_{min} = r\left[\frac{T_L - T_\infty}{5.38}\right]^{\frac{3}{2}} H^{\frac{3}{2}} \quad for\, \frac{r}{H} > 0.18$$

As an example, consider an industry having a ceiling height of H = 10 m, a fire detector is place at a distance of r = 4 m from plume axis, and let T_L and T_∞ are 60 °C and 20°C, respectively. The minimum size of fire that can be detected can be calculated as 2.56 MW.

Fire detector analysis:

Rate of heat transfer to the detector is hAΔT. Then, considering lumped formulation, where the conduction resistance within the detector is taken as negligible, the governing equation is written as,

$Mc \times dT_d/dt = hA(T_g - T_d)$,

where T_d and T_g is detector and gas temperatures; T_g, is generally constant. Considering temperature increase with respect to ambient temperature, T_∞, the governing equation is written as,

$$\frac{d(T_d - T_\infty)}{dt} = \frac{hA}{Mc}\left[\left(T_g - T_\infty\right) - (T_d - T_\infty)\right]$$

$$\frac{d\left(\Delta T_d/\Delta T_g\right)}{dt} = \frac{hA}{Mc}\left[1 - \left(\frac{\Delta T_d}{\Delta T_g}\right)\right] = \frac{1}{\tau}\left[1 - \left(\frac{\Delta T_d}{\Delta T_g}\right)\right]$$

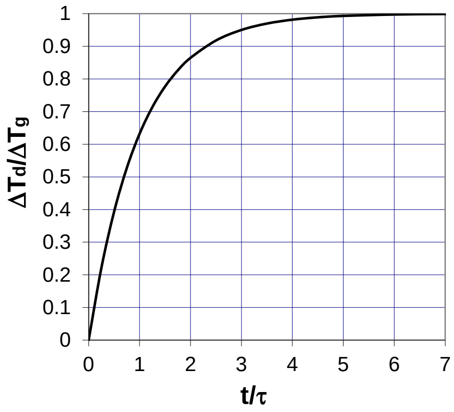
Here, $\Delta T_g = T_g - T_\infty$, $\Delta T_d = T_d - T_\infty$ & $\tau = Mc/hA$, is time constant.

Time required for activating fire detector:

Time constant (τ) is not really a constant due to presence of h. Here, h depends approximately on $(u)^{1/2}$. The governing equation is analytically solved to get,

$$\frac{\Delta T_d}{\Delta T_g} = 1 - e^{-\frac{t}{\tau}}$$

For a detector, a plunge test is carried out by placing it in a stream of hot air flowing at temperature T_0 & velocity u_0, and value of time constant (τ) is determined.



If $T_d \rightarrow T_{activation}$, then $t \rightarrow t_{activation}$.

Response Time Index (RTI):

Response time index (RTI) (Heskestad and Smith,1976) is defined as: **RTI =** $\boldsymbol{\tau_0 (u_0)^{1/2}}$. Its unit is $\mathbf{m^{1/2}s^{1/2}}$. Here, $\boldsymbol{\tau_0}$ is the time constant using plunge test. Ceiling jets close to the detector is assumed laminar. For most flows, it can be shown that $\mathbf{h_0 \sim (u_0)^{1/2}}$. Thus, **RTI =** $\boldsymbol{\tau_0 h_0}$ **= Mc/A**. Also, **RTI =** $\boldsymbol{\tau u^{1/2}}$ **= constant =** $\boldsymbol{\tau_0 (u_0)^{1/2}}$. Or $\boldsymbol{\tau_0 = \mathrm{RTI}/u_0^{1/2}}$.

Analytical solution is given as:

$$\frac{\Delta T_d}{\Delta T_g} = 1 - e^{-\frac{t}{\tau}} = 1 - e^{-\frac{t}{RTI}u^{1/2}}$$

Time history of T_d and response time is got using values of RTI, and $T_g(t)$ & u(t) evaluated from the Alpert correlations.

Useful correlations for temperature and velocity:

$T_g(t)$ & u(t) evaluated from the Alpert correlations.

$$\Delta T_{g,plume} = 16.9\frac{\dot{Q}^{2/3}}{H^{5/3}}$$

$$\frac{\Delta T_{g,ceiling\ jet}}{\Delta T_{g,plume}} = \frac{0.32}{\left(\frac{r}{H}\right)^{2/3}}$$

$$u_{g,plume} = 0.95\frac{\dot{Q}^{1/3}}{H^{1/3}}$$

$$\frac{u_{g,ceiling\ jet}}{u_{g,plume}} = \frac{0.2}{\left(\frac{r}{H}\right)^{5/6}}$$

Values of $T_g(t)$ & u(t) are evaluated using above expressions. Lower the value of RTI, faster is the response. Lower the value of M or c, lower will be the value of RTI. Higher the value of h or A, lower will be value of RTI.

Fire alarm:

The fire alarm is a signalling system that would broadcast the presence of fire in a building based on the trigger from detectors or that initiated by a manual trigger. The purpose of a fire alarm is to evacuate the people from the fire scene and to protect human life. Based on NFPA 72. It is also used to notify fire service so that the fire can extinguished within a reasonable time and structure is also protected. Fire alarm system has central system, control circuits and control panel: The signal from detectors and/or manual trigger is sent to a central system from which activation of audible as well as visual alarms, sprinklers and so on is done through suitable circuits. All required electronic systems are present in the control panel. Proper primary and secondary power supply are provided to the fire alarm system.