**Course Name: Theory of Fire Propagation (Fire Dynamics)**

**Professor's Name: Dr. V. Raghavan**

**Department Name: Mechanical Engineering**

**Institute: Indian Institute of Technology Madras, Chennai – 600036**

**Week – 12**

**Lecture – 05**

# Module 9 – Fire safety aspects

Fire suppression:

Recalling the fire triangle, if one or more of the three components, fuel, oxidizer or heat, are not available, fire ceases to exist. Fire suppression involves methods to remove or significantly reduce one or more of these three components. Fire can also be suppressed if the chemical reaction between the fuel and oxidizer is inhibited. The chemical reaction rate in $kg/m^3s$ is written as:

$$\dot{\omega}''' = \rho Y_F^n Y_O^m \exp\left(-\frac{E_a}{R_u T}\right)$$

**Thermal sink effect** – reduces temperature and water spayed on solid fuel reduces fuel supply (fuel concentration).

**Oxygen displacement** – sprinkler, water mist, gas injection, etc., reduces oxygen concentration and flame temperature.

**Chemical inhibition** – halons, directly affects chemical kinetics.

Fire extinguishing agents:

| Type of agent | Solid fuel (wood, paper, cloth) | Liquid fuels | Gas fuels | Electrical devices | Cooking oil, fats, organic matter | Remarks |
|---|---|---|---|---|---|---|
| Water (sprinkler, mist) | Yes | No | No | No | No | Dangerous to use in liquid and electrical |
| Foam | Yes | Yes | No | No | Yes | Not for homes |
| Dry powder | Yes | Yes | Yes | Yes | No | Nil |
| $CO_2$ | No | Yes | No | Yes | Yes | Nil |
| Halon | Yes | Yes | Yes | Yes | Yes | Banned |

Water based system:

Imparts thermal sink effect; primarily reduces the temperature. Water vaporizes, contributing to water vapor generation and dilution of fuel (gas & vapor) and oxygen – oxygen displacement. Water injected on solid fuel surface reduces pyrolysis and fuel generation. Also, inhibits surface reaction in charring fuels. Sprinkler system and water mist system are used to **control fire**.

**Sprinkler system** – simple, low cost, low maintenance and uses high water discharge (≈15 litres per minute per square meter).

**Water mists** – costlier, high maintenance, needs high pressure systems, imparts high penetration, much lower discharge rates (three orders of magnitude lesser than sprinkler).

Fire fighters use water jets connected to hydrants to quench much larger fires. These have much higher flow rates. Cleaning after quenching a fire may be tedious.

Sprinklers:

Sprinklers are expected to-

i) Increase the time taken to reach flashover.

ii) Decrease the concentrations of emissions such as CO, HCN, etc.

iii) Decrease the room temperature.

iv) Push the smoke layer down to dilute oxygen – slow down the fire growth.

v) Carry down or dissolve soot particles and improve visibility.

vi) Sprinklers are designed based on standards; (NFPA 13)

vii) Identification of fuel load and water quantity.

viii) Purpose of building (occupancy); choosing sprinkler type.

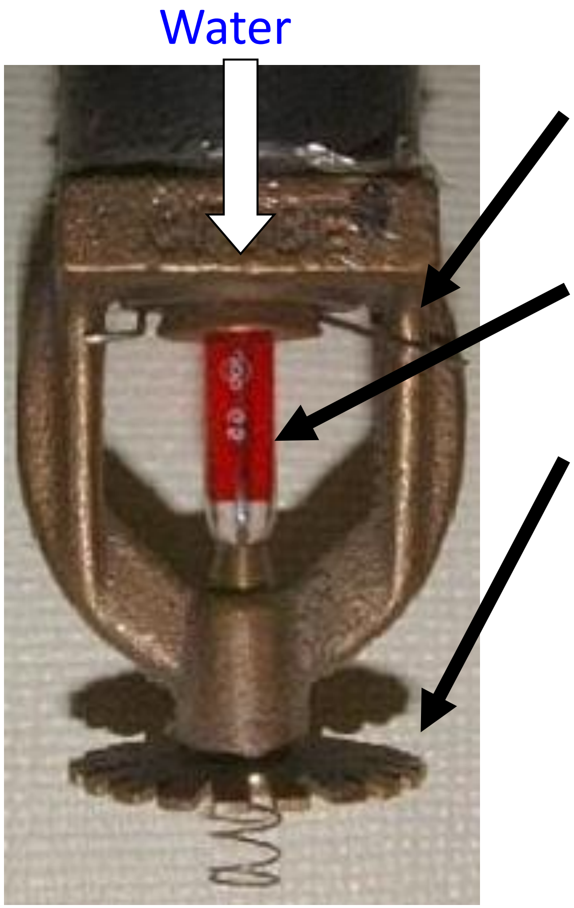
ix) Sprinkler density (water flow rate per unit area).

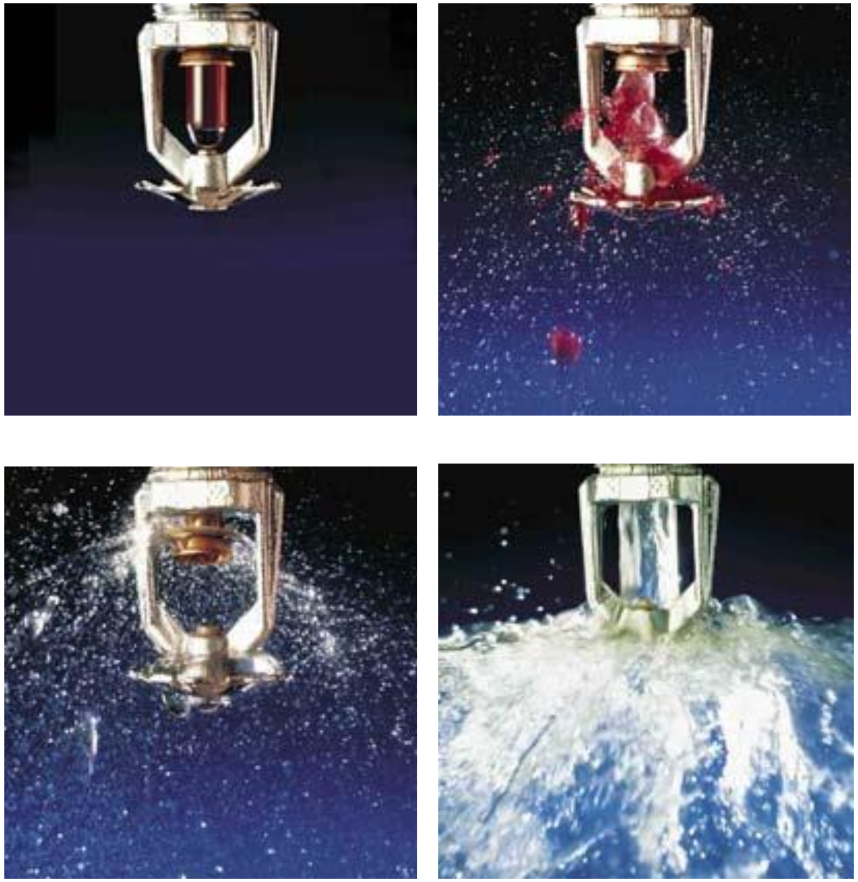
x) Sprinkler placement in specified locations in ceiling.

xi) Choosing auxiliary components; pumps, pipes, valves, etc.

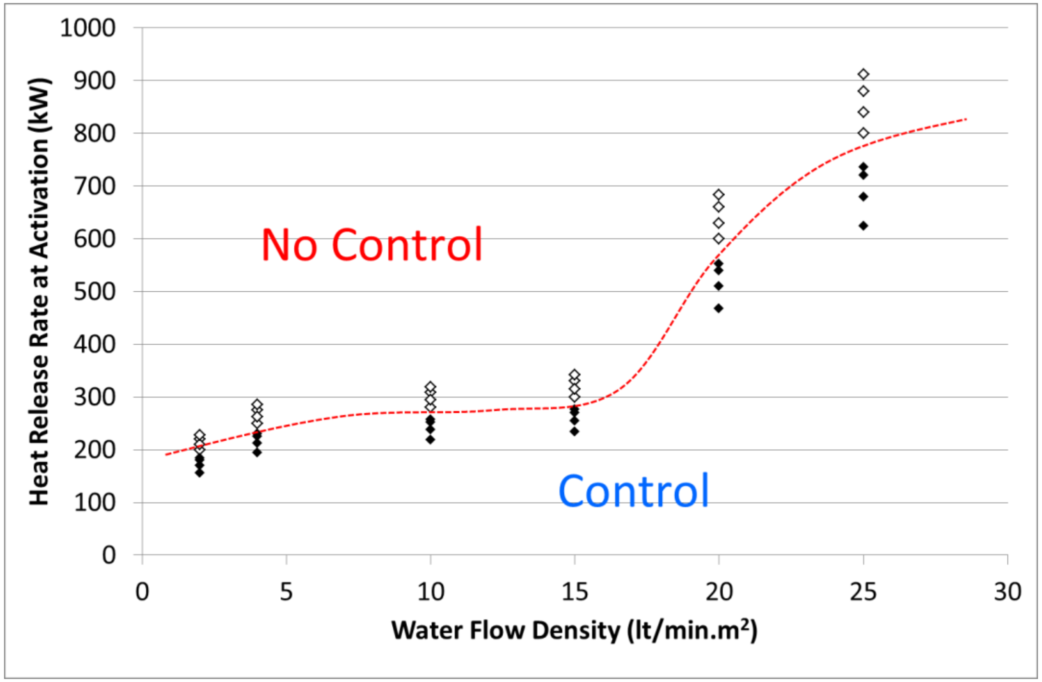
Sprinkler activation:

(From GIAN course of Prof. Jose Torero)


Water
Structure
Fusible Link
Deflector



Sprinkler performance:



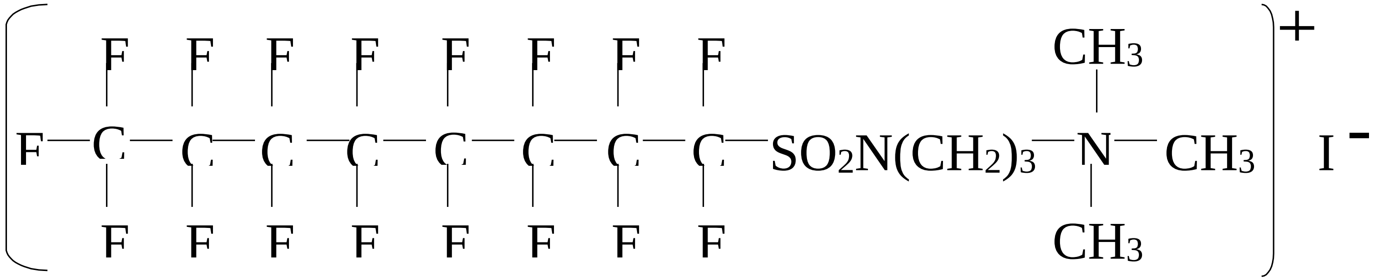

(From GIAN course of Prof. Jose Torero)

Sprinklers:

If $A_0$ is the area (in $m^2$) of the building/compartment covered by sprinklers and sprinkler density, which is water flow density in litre/(minute-$m^2$) is $\dot{V}''_{crit}$, the total water flow rate in litre/minute is calculated as, $\dot{V}_{crit} = A_0\dot{V}''_{crit}$. If water flow rate in litre/minute through one sprinkler is $\dot{V}_S$, then the number of sprinklers required in the given area is estimated as, $\mathrm{N} = \dot{V}_{crit}/\dot{V}_S$. Amount of water required ($\dot{V}_{crit}$) is estimated using fire load and specified as water density. Volumetric flow rate of water through one sprinkler ($\dot{V}_S$) is estimated as, $\dot{V}_S = K\sqrt{\Delta p}$. Here, K is simply called a K-factor, which is taken from standard tables, and $\Delta p$ is the pressure drop.

Foams:

Foams are used to extinguish fire over liquid fuels. Generally based on fluorine and iodides. Aqueous film forming form (AFFF), Film Forming Fluoro-Protein (FFFP) foam are generally used as extinguishers. Forms a film over the fuel surface, spreads over the surface and covers the fuel surface. It imparts low cooling effect.




(AFFF, from GIAN course of Prof. Jose Torero)

Dry chemicals:

Used for rapid extinguishing of fires by introducing the dry chemical agent into the flaming area. Available in portable cylinders for one time discharge. If dry chemical is halogen based, it acts as chemical inhibitor, else only acts as a thermal sink. These can be corrosive in nature, but not toxic. These commonly contain sodium bicarbonate, potassium bicarbonate, urea-potassium bicarbonate, etc. Cleaning process after extinguishing can be tedious.

Carbon dioxide:

Used commonly against kitchen fires. Generally $CO_2$ is supplied through pipelines as liquid; pressurized to around 5 bar (gauge), care is taken to ensure pressure levels to avoid the formation of dry ice (solid $CO_2$).When liquid $CO_2$ is discharged to atmospheric pressure, it flash vaporizes to superheated vapor with low temperature. Since denser than air, it can provide blanket effect by covering the fuel surface. Thus, both oxygen and fuel vapours are diluted. It does not provide much of thermal sink effect.

Halon:

Highly effective – chemically participates and supresses. Affects the chain branching reaction where multiple radicals are produced and decelerates the reaction. Cleaning after extinguishing the fire is easier. Most effective gas suppressant is Halon 1301, which is $CF_3Br$. Halon 1301 reacts with active radicals such as **H** and **OH**.

$$\mathbf{CF_3Br + M \rightarrow CF_3 + Br + M}$$

**Br + H → HBr**

**HBr + OH → $H_2O$ + Br**

Halon 1301 released to the atmosphere splits and releases Br when subjected to UV radiation. **Br** reacts with ozone (**$O_3$**) to form **BrO** and **$O_2$**. Thus, ozone gets depleted. Therefore, Montreal protocol has banned the manufacturing and use of Halon 1301.