Introduction to Fire & Safety Engineering

Semester VII

Course Code: 2CHOE26

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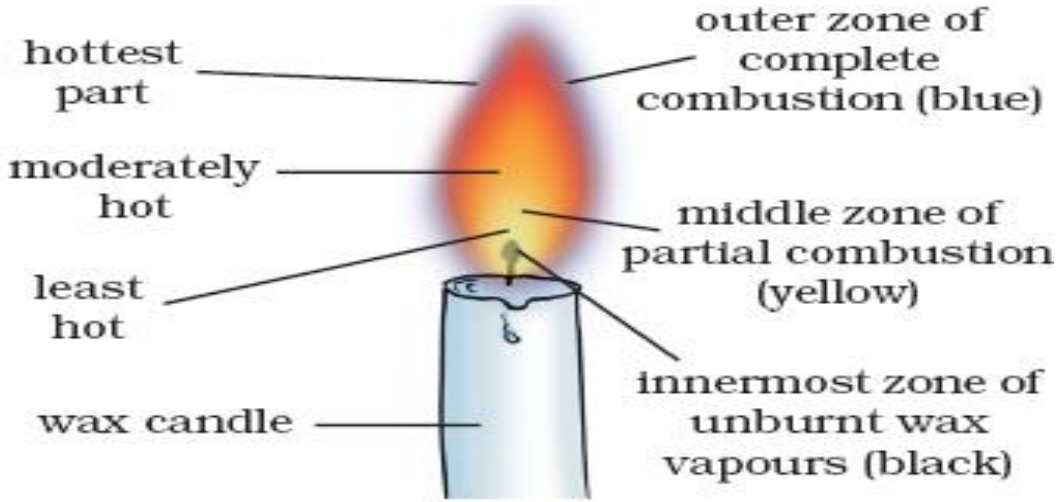
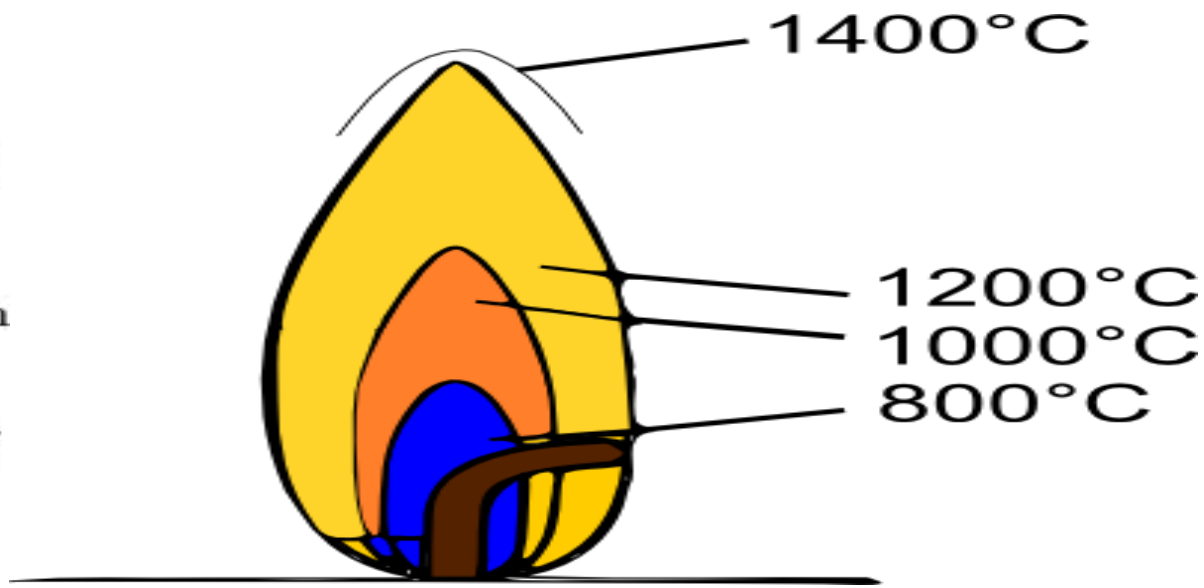
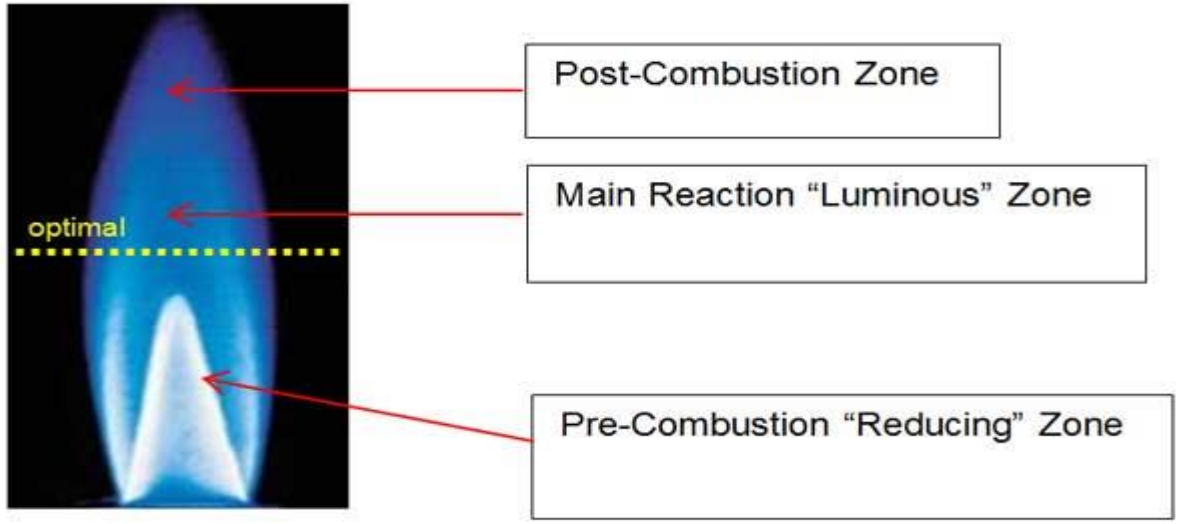
UNIT 2: The Fire Process

Introduction of flames







Understanding the flame

Oxidizing vs Reducing flame

	Oxidizing Flame	Reducing Flame
DEFINITION	Oxidizing flame is the burner flame that is produced in the presence of an excessive amount of oxygen gas	Reducing flame is the burner flame that is produced in the presence of a low level of oxygen gas around the burner
APPEARANCE	Dark colours	Yellow or yellowish flame
OXYGEN LEVEL	Forms when there is excess oxygen	Forms when there is a low level of oxygen
REDOX ABILITY	Can oxidize metal surfaces	Can reduce molten metal
SOLDERING AND ANNEALING	Not suitable	Suitable
FLAME SIZE	Short	Long

How fire takes place?

- Generally, the process of burning in language of science is called process of combustion and initiation of combustion is called ignition.
- Remember……Combustion process is actually the oxidation process but not all oxidation processes are combustion processes.
- Combustion involves the reaction of a fuel with oxygen and release of heat.

$$\text{Fuel} + \text{Oxygen} \xrightarrow[\text{(Activation energy)}]{\text{In the presence of heat}} \text{Products of combustion} \quad \textit{(With release of heat of combustion)}$$

- The chemical equation below illustrates the combustion of carbon:

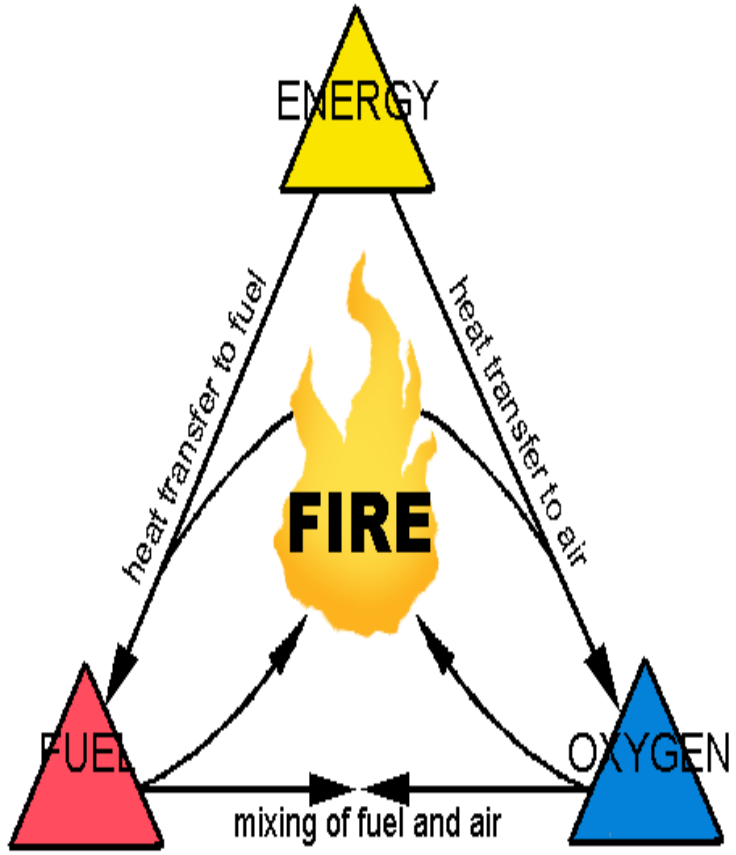
$$C + O_2 \xrightarrow[\text{(Activation energy)}]{\text{In the presence of heat}} CO_2 + \text{Heat of combustion}$$

- As an exception, Magnesium burns in the atmosphere of nitrogen to give its nitride.

$$4Mg + 3N_2 \xrightarrow[\text{(Activation energy)}]{\text{In the presence of heat}} 2Mg_2N_3 \quad \textit{(With release of heat of combustion)}$$

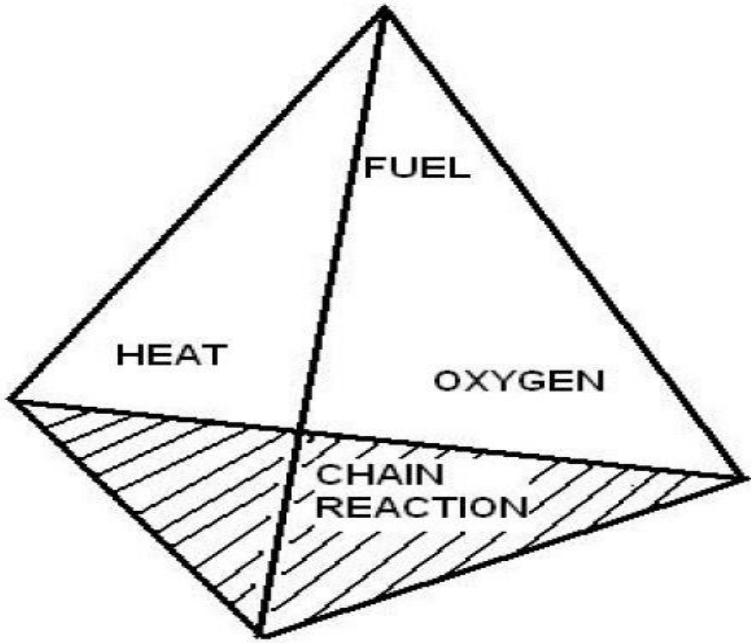
Fire Triangle

- Three components are required for fire:
  - Fuel in its right concentration
  - Combustion supporting medium (Oxygen / Air)
  - Adequate energy in the form of heat
- These three components are represented as sides of triangle which is known as fire triangle.
- If any one component is removed, fire is not possible.



Fire Tetrahedron

- Fire triangle can be used to explain the ignition process. But it can not adequately depict the fire growth and extinguishment of the flame.
- Fire process involves the chain reaction during the combustion process which occurs in flame region where the vapor formation takes place. (not in gases)
- The fire will sustain until the chain reaction stops, which led to the fourth component of fire process and that is fire chain reaction and due to this fourth component, it is called fire tetrahedron.
- This fire tetrahedron is 3D figure represented by a pyramid with a triangle base.
- Basically chain reaction is nothing but the fire itself.




THE FIRE TRIANGLE


CLASSROOM INVESIGATION /01
FIRE TRIANGLE


RE-RESCUE

Fule

- Fuels are in three states: Solid, Liquid and Gas. All these states differ in their ignition sequence. Obviously gas will ignite first and solid will last.
- Adequate quantity of fuel vapor will combine with oxygen/air and adequate amount of energy is obtained, the fire will take place.
- Gaseous fuels will not need to go through the process of vaporization as they are already in gas phase and directly catch the fire once ignition is given.
- Liquid fuels will be first converted into the vapor phase and then it will catch the fire.
- There are different modes of burning a liquid fuel: Pool fire, annular ring fire, flowing fire, spray fire, wick burning fire etc.
- Solid fuels will have to pass through the liquefaction process first followed by vaporization process. But some solids are directly converted to vapor phase like camphor is known as sublimation which can cause fire very rapidly compared to other solids.

Smoldering

- **Smouldering** (British English) or **smoldering** (American English) is the slow, flameless form of combustion, sustained by the heat evolved when oxygen directly attacks the surface of a condensed-phase fuel.
- Coal, cellulose, wood, jute, cotton, tobacco, peat, synthetic foams, charring polymers and some types of saw dust.
- Common examples of smouldering phenomena are the initiation of residential fires on furniture by weak heat sources (e.g., a cigarette, a short-circuited wire) and the persistent combustion of biomass behind the flaming front of wildfires.
- The chain of event: Discoloration of material > Evolution of vapor > glowing chare formation > production of residue or ash till the conditions are in favor of fire.
- It is seen in solid fuels only but as an exception some heavy petroleum oil can also show this phenomenon.

Metal Fire

- Metals, generally are not fuels but some metals or metal salts are combustible.
- E.g. Lithium, Sodium, Potassium, Cesium, Rubidium, metals catche fire if comes in contact with air or water.
- Aluminum and magnesium powder also burns vigorously and therefore used in the preparation of explosives and in pyro techniques.
- Magnesium can burn in the atmosphere of nitrogen.
- Thus, some metals can also be used as fuel but their combustion process can’t be generalize with other fuels as it may vary from the regular fuels and the products are also different.
- Obviously, the fire fighting techniques are also different for metal fire.

MELT/POUR

Aluminum Metal, Still More Expensive Than Energy

Combustion of Dusts and Ease of Ignition

- Combustible dusts are more risky to the fire than its larger size of solid.
- E.g. Grain husk, saw dust etc. when present in the form of bed, they can burn rapidly as per the chemical kinetics principle of larger surface area.
- First the smoldering will be observed on the dust surface area and then will catch fire properly.
- Some combustible dusts are probe to explode if it is in the form of dispersed cloud.
- For the dust explosions to occur, the concentration of dust in air should be within explosive limits which is similar to the flammable range of vapors or gases accompanied with source of energy such as a spark or spontaneous heating.
- Dust explosions occur in series so it is really dangerous to handle.

- Fuels need to vaporize and combine with air before the ignition which actually requires either thermal or mechanical energy.
- As compared to wood log, saw dust will ignite very easily because of larger surface area and the ease of vapor generation depends upon the surface area to volume ratio.
- Greater the ratio, lower the energy is required for the ignition.
- Heavy oils can be discharged through the nozzle spray to facilitate the burning.
- In industrial furnaces and boilers, higher ratio can be effectively used for the oil-fire or pulverized coal-fire.

$$\text{Ease of ignition} \propto (\text{Surface Area/Volume})$$



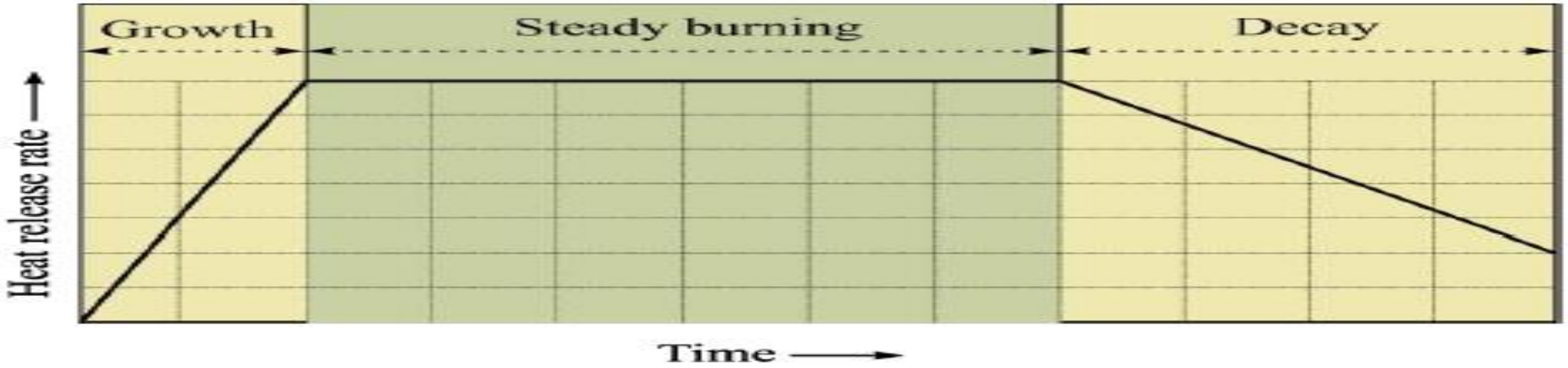



Ignition Process and Thermal Feedback

- Without heat, fire is not possible along with fuel and air.
- When we lighten the candle wick with match stick, the process will go through several steps given below:
  - Soften and melt the wax which then goes up the wick by the capillary action.
  - Generation of wax vapors
  - Vapors combine with air to form air-vapor mixture.
  - With the help of heat then ignite the flammable air-vapor mixture.
- This happens in such a rapid sequence that one can not observe it or judge it and all they appear to take place in a flash and after that, even removing the match stick the above mentioned process will take place with heat from flame and burning is sustained.
- Similarly fuels other than candle may be ignited in different ways but, once ignited, thermal feedback is essential for sustained burning along with adequate air.
- If heat is removed the fire will decay or die out even though fuel and air is present.

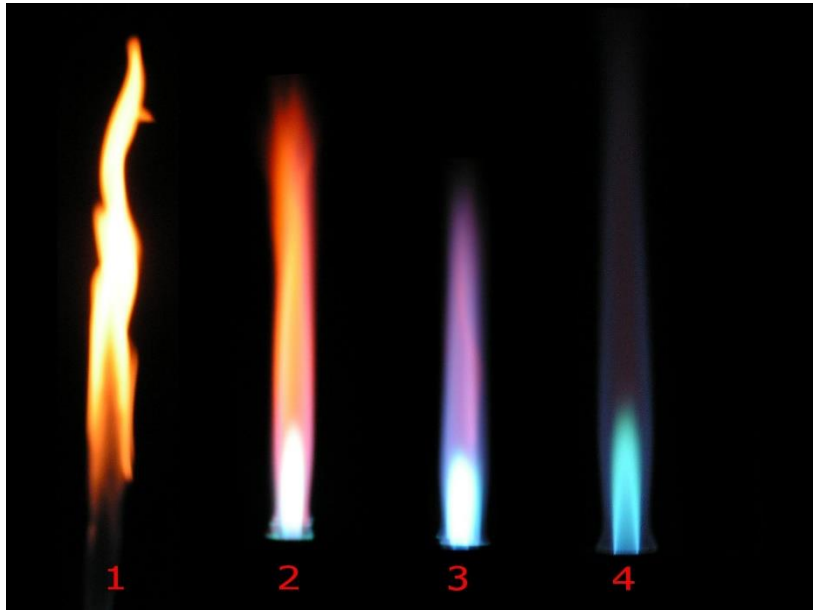
Fire Stages

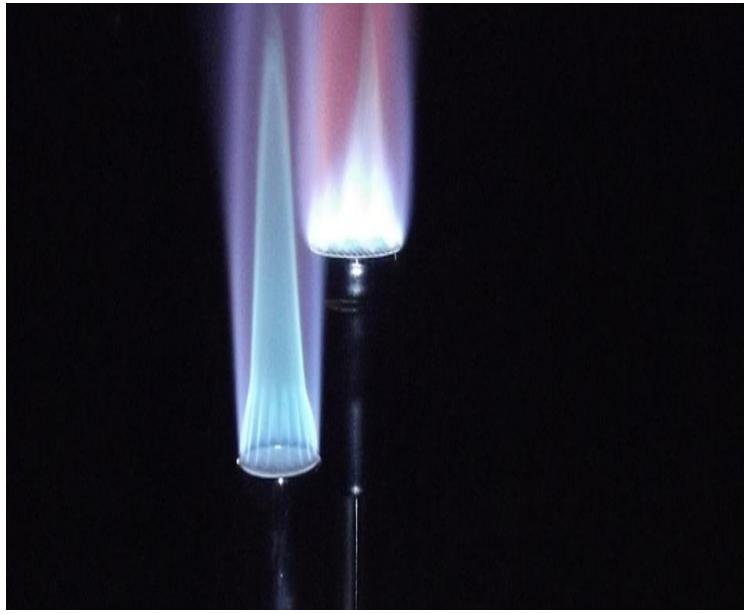
- The life cycle of a fire starts with ignition, followed by growth and steady burning and ends with decay of fire. Therefore there are three stages of fire:
- First: Ignition and Growth, Second: Steady burning Third: Decay
- These stages are described in the terms of heat output.
- In first stage the temperature increases.
- In second stage there is no further rise in temperature and heat release output is same.
- In last stages finally the temperature will start decreasing. (Fuel is exhausted or no air)
- The rate of heat released can be depicted by the figure given below:



Structure of Flame

- Without heat along with fuel and air, fire is not possible.
  - Premixed flame: Premixed flames occur in any homogeneous mixture where the fuel and the oxidant are mixed prior to the reaction.
    - E.g. Bunsen burner flame and the flame in most spark-ignited engines. blue coloured flame due to excited CH radical. Fuel rich mixture: green coloured flame due to excitation of C2 molecule. Highly fuel rich mixture: yellow coloured flame due to soot formation.





- Buoyant diffusion flame: The hot flame heats the unburned fuel bed, which subsequently vaporizes. The resulting fuel vapour reacts with the oxygen supplied by the incoming air, thereby producing the heat that maintains the flame-spread process.
  - E.g. candle flame is a classical example of a diffusion flame. The flame reaches a steady state almost immediately after a match is brought up close to the wick and if the air in the room is sufficiently still, it does little flickering. The flame basically remains constant in shape and size with orange-yellow colour.

Premixed Flame from a Gas Stove

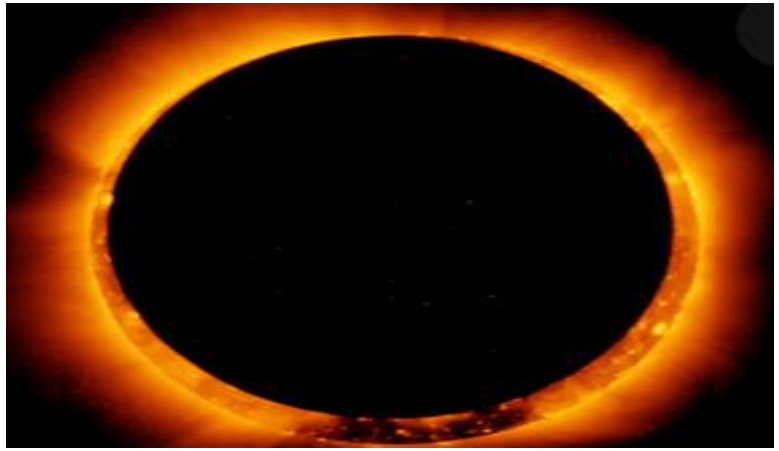
Diffusion Flame from a Lighter

Different Types of Fire

Spray fire

Wick fire

Pool fire

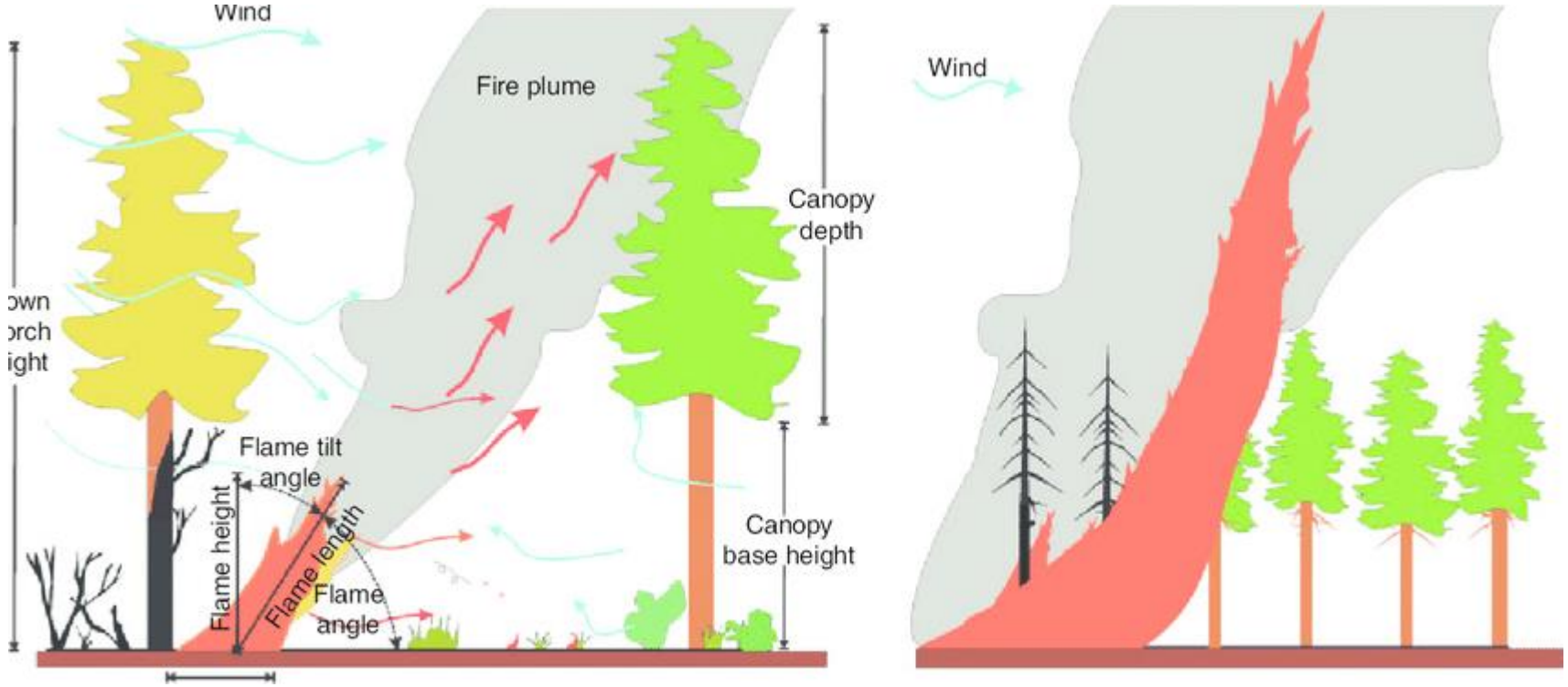


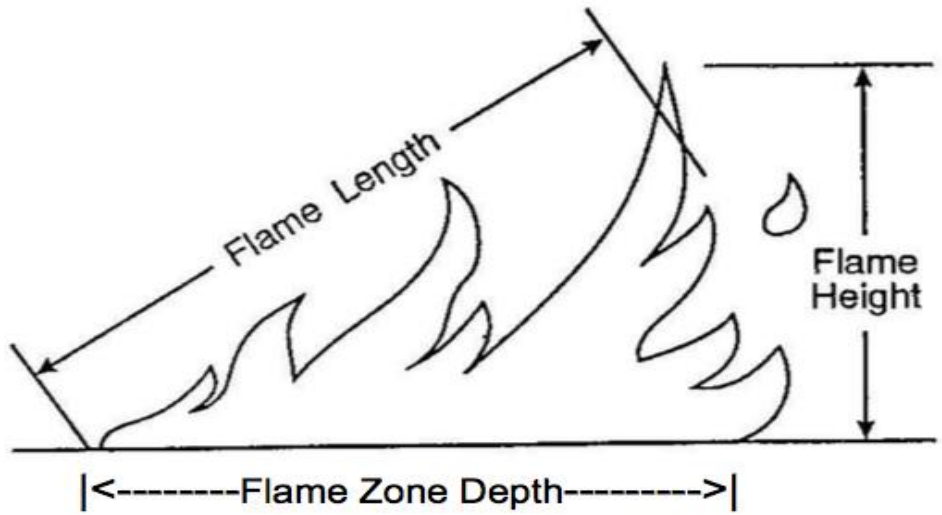
Annular ring fire

Flowing fire

Flame height / length

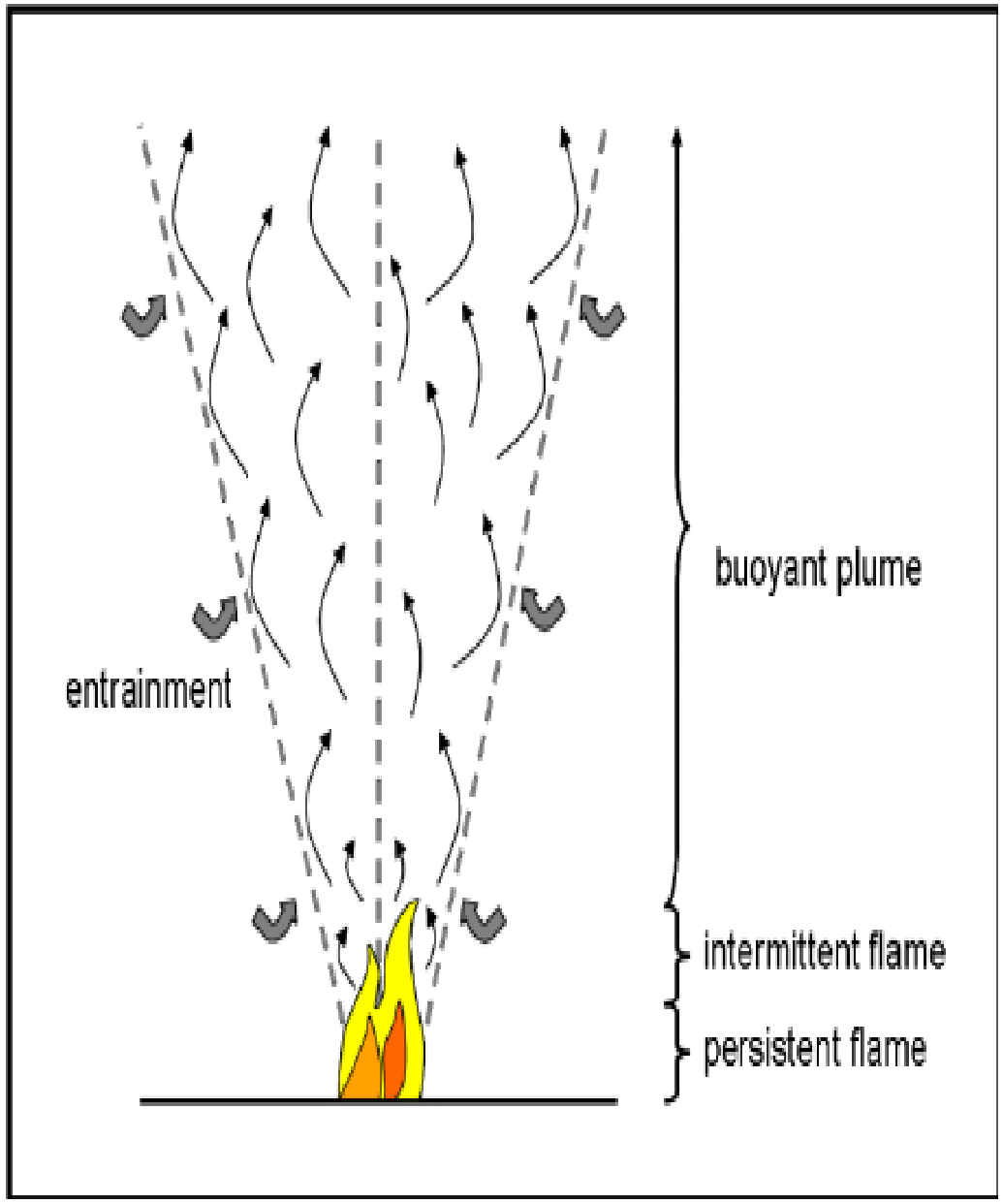
- Flame shape and size is the major parameter for the determination of damage potential of fire.
- Flame height which is also known as flame length depends on numerous parameters such as, type of fuel, ambient condition, ventilation, air supply etc.
- Flame height and length may be same for a vertical fire but may not be same for a tilted fire due to prevailing conditions.
- Due to this, the height and vertical surface area of the flame cylinder is very important in case of fire.
- It again depends on the angle of tilt of the flame cylinder, separating distance between the flame and a target object, view factor, attenuating conditions etc.
- So considering all these factors the height / length of the fire are the major parameters to be considered while determining the damage in any incident due to the fire.

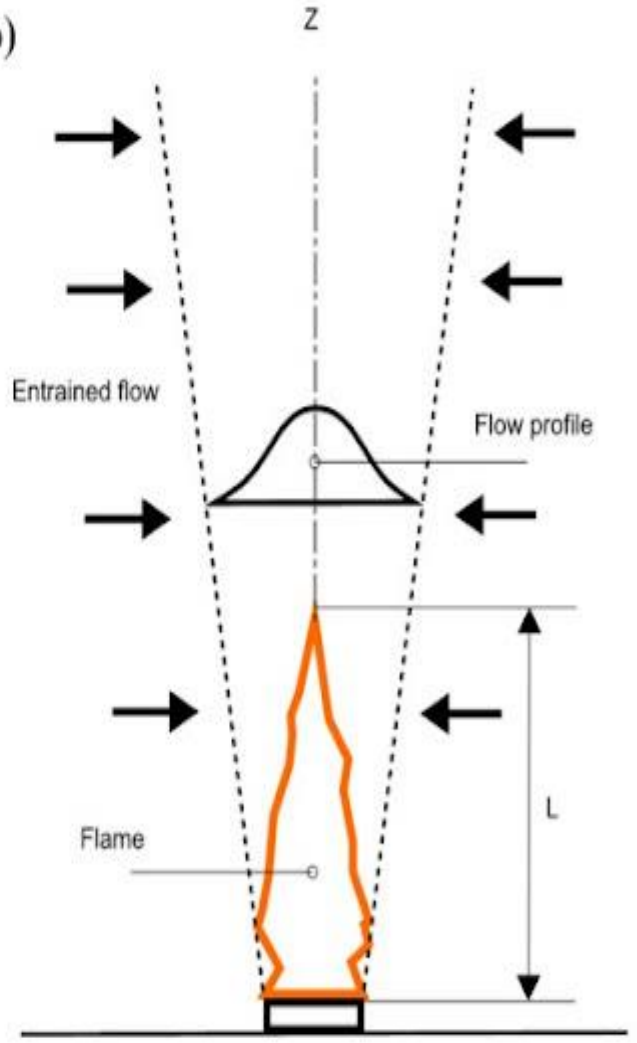

Wind
Fire plume
Canopy depth
Flame tilt angle
Flame height
Flame length
Flame angle
Canopy base height
Wind


Flame Length
Flame Height
|<--------Flame Zone Depth--------->|

Fire Plume

- The nature of flame may be either laminar diffusion or turbulent depending on the velocity of the gas released at the point.
- The fire plume is the motion generated by a source of buoyancy exists by virtue of combustion.
- Fire plume has three distinct regimes viz.
  - Persistent flame just above the burner surface with accelerating flow of burning gases which is known as flame zone.
  - Intermittent flame and near constant flow velocity
  - Buoyant plume in which velocity and temperature decreases with height and time.
  - The rising hot products of combustion of a buoyant diffusion flame set up is termed as a buoyant plume, which continues to rise till the temperature differentials or an overhead ceiling prevent it from rising further.
  - When it reaches the ceiling, it starts spreading to form is called hot ceiling layer.
  - It is important to understand this as fire protection systems are designed on this phenomenon.

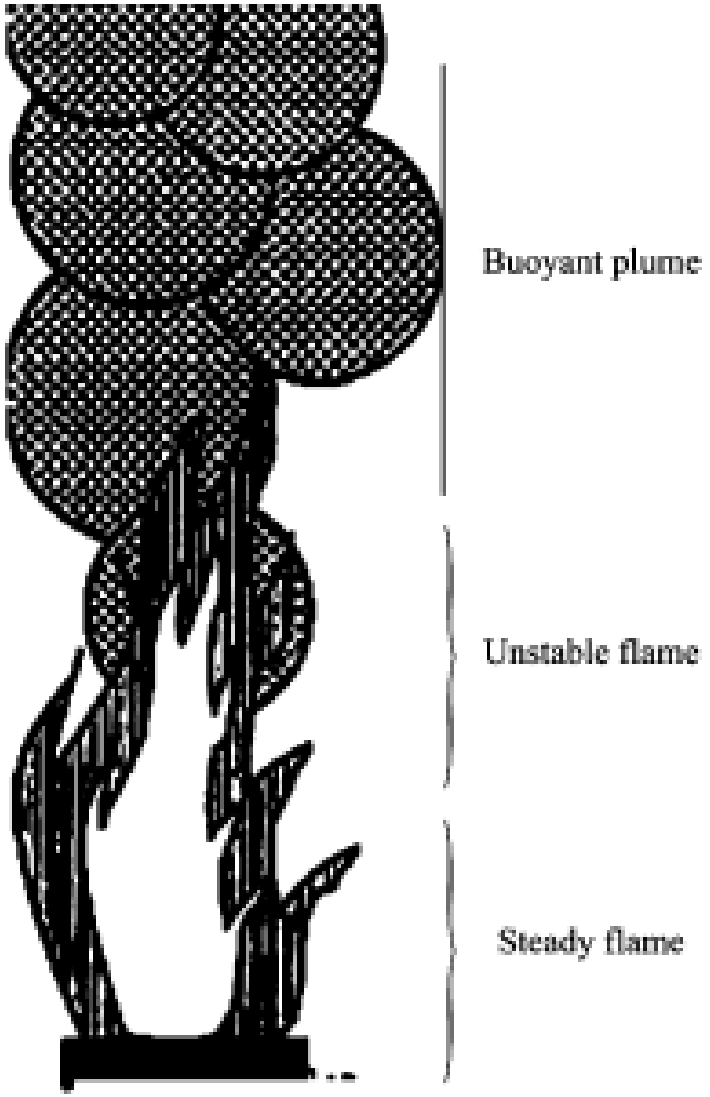


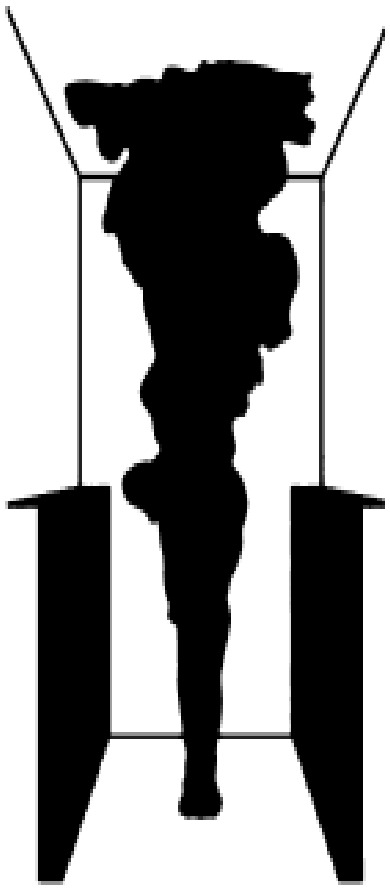


The analytical representation of fire plume

Plume Features

- At the burning surface, the cross section of the flame covers entire surface but at a height above the fuel surface, the shape is irregular due to flickering of flame.
- For the purpose of calculations, the flame is generally assumed to be a vertical cylinder.
- The shape of plume created by fire assumes the shape of an inverted cone that gets widen with an elevation of fire.
- The velocity is maximum in upward direction and minimum at the lower edge of the plume.
- This central axial velocity is maximum at a point within the flame and then falls with height.
- With respect to temperature of flame, it remains constant in the lower portion of the flame and starts falling with height from the intermittent section of the flame.
- Behavior of plume in a closed area depends on ceiling height, compartment size, doors, windows or ventilation etc. But in open area plume behavior will be affected by air movement, prevailing wind, ambient temperature etc.





Fire plume in closed area and open area

Flame Progression

- On an open liquid pool, once source of ignition is introduced at one point, the flame will spreads across the entire surface.
- In a small pool, it may appear that the entire surface has got ignited at a single moment but the spreads may be visible and evident in case of a large pool.
- Surface flame spread on a solid fuel surface can in most cases be conveniently observed.
- In the case of liquid, fire takes place very rapidly at the same moment.
- Progress of flame within a fuel-air vapor cloud in the open would depend on the concentration of the cloud, the size of the cloud and many other factors.

Thank You