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Study Text

NEBOSH
Certificate in Fire Safety
Units FSC1 and FSC2

nebosh

LEARNING PARTNER
GOLD 335

The Principles of Combustion, Fire Growth and Fire Spread

IN THIS SECTION...

The combustion process:

- Can be illustrated by the fire triangle, which requires fuel, heat and oxygen to initiate and sustain a fire.
- Is a chemical reaction whereby volatile molecules of fuel react with oxygen, either completely or partially, to generate combustion products.
- Generates heat and is termed 'exothermic'.
- Progresses through the stages of induction, ignition, fire growth, steady state, and decay.

Fire Triangle

To initiate and sustain a fire, three things need to be present at the same time:

- **Fuel** - such as wood, paper, plastic, petrol.
- **Oxygen** - usually from the air, but also from gas cylinders or oxidising agents.
- **Heat** - from ignition sources such as open flames, friction, chemical reactions, sparks from electrical equipment.

The fire triangle

If we remove one element from the triangle, fire will not be initiated or sustained:

- If **fuel** is not available or removed, the fire will not start or an existing fire will go out.
- If **oxygen** is absent or removed, the combustion process will not proceed.
- If **heat** from ignition sources is not available, the fire will not start and if heat is removed by cooling, the fire will be extinguished.

Chemistry of Combustion

DEFINITION

COMBUSTION

A type of chemical reaction - a rapid, self-sustaining gas-phase oxidation process which produces heat and light.

When combustion takes place in solids or liquids, it is the vapours given off that ignite, rather than the solid or liquid itself.

Put simply, volatile (vaporised) molecules of the fuel are combined with oxygen to produce new compounds (combustion products).

For the combustion process to proceed and be maintained:

- Energy (heat) is required to vaporise sufficient fuel molecules and to initiate the reaction. Once initiated, the heat produced by the reaction itself will sustain further vaporisation and combustion of fuel without an external heat source.
- A continued supply of fuel and oxygen is required to replace that consumed by the reaction.

Combustion Products in Relation to Combustion Reaction Conditions

In **complete combustion** - fuel reacts with oxygen and both are completely consumed in the reaction to form new products:

- Methane burns in air:

  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

  to produce carbon dioxide and water only.

- Hydrogen burns in air:

  $2H_2 + O_2 \rightarrow 2H_2O(g)$

  to produce water vapour only.

In **incomplete combustion** - fuel reacts with limited oxygen so the combustion of the fuel is not complete:

- Methane burns in limited air:

  $4CH_4 + 6O_2 \rightarrow CO_2 + 2CO + C + 8H_2O$

  to produce carbon dioxide and water, but also carbon monoxide and pure carbon (soot or ash) due to the reduced oxygen supply and the inability for full oxidation to carbon dioxide and water.

Exothermic Reaction

The combustion process generates heat as it progresses so this type of chemical reaction is called exothermic, 'exo' (give out) 'thermic' (heat). It is also possible for chemical reactions to require an input of heat to progress and these are called endothermic, 'endo' (take in) 'thermic' (heat) reactions.

TOPIC FOCUS

Chemical reactions can be either exothermic or endothermic:

- **Exothermic reactions**:
  - Release energy in the form of heat, light or sound.
  - Cause an increase in temperature.
  - Can occur spontaneously.
  - May produce heat quickly and can cause explosions.
- **Endothermic reactions**:
  - Absorb energy from the surroundings to proceed.
  - Cause a drop in temperature.
  - Cannot occur spontaneously.

Oxidising Agents/Materials

Combustion requires the presence of oxygen, so the higher the concentration of oxygen in an atmosphere, the more rapidly burning will proceed.

Whilst the most common source of oxygen is obviously the air, in some workplaces there may also be additional sources which can provide a fire with oxygen and so help it burn. These include:

- Oxygen cylinders.
- Oxidising agents, e.g. chlorates, chromates, hypochlorites, nitrates, nitric acid, peroxides and peroxyacids.

Methods of Heat Transfer

A fire will initially spread by **direct burning**, where there is direct contact between the burning material and the new fuel source.

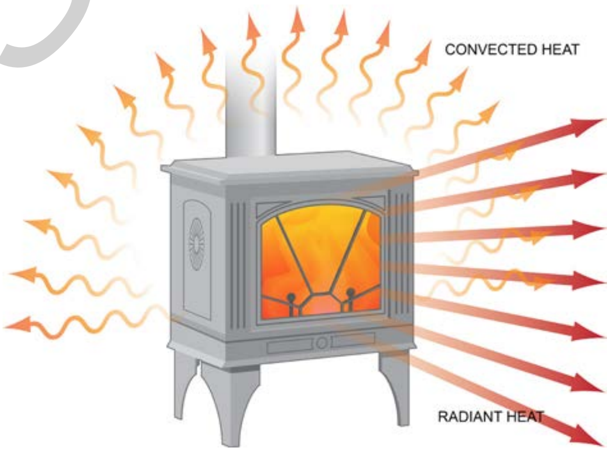
Once established, **conduction** may allow heat transfer through conducting materials to ignite fuel that is remote from the original fire.

Conduction

Convection currents, generated by heated gases expanding, becoming less dense and rising, will transfer heat to surfaces above the fire, such as ceilings and ductwork.

Convection currents

The heated materials in a fire will radiate heat (thermal **radiation** or infrared) which can be absorbed by surfaces near the seat of the fire and cause ignition of nearby fuel.



Radiant heat

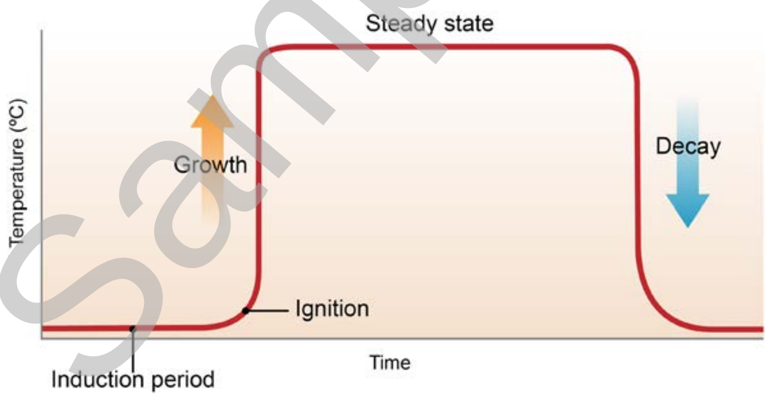
TOPIC FOCUS

The **FOUR** methods by which heat may be transferred during a fire are:

- **Conduction**
  - Molecule-to-molecule transfer of heat through conducting solids such as metal beams or pipes.
  - Heat is transferred to other parts of the building and can ignite combustible or flammable materials.
- **Convection**
  - Hot gases rise and become trapped beneath a ceiling or travel through voids and ducts to other parts of a building.
  - The hot gases ignite combustible or flammable materials.
- **Radiation**
  - Heat is emitted in the form of infrared radiation.
  - Radiant heat can raise the temperature of adjacent materials to above their ignition temperatures or flash points.
- **Direct Burning**
  - Heat comes in direct contact with combustible materials.
  - Direct contact causes ignition.

Stages of Fire

You can see the combustion process illustrated in the following figure:



The stages of combustion

- **Induction** - heat produces sufficient vapour which can mix with air above the fuel and generate a flammable mixture.
- **Ignition** - initiates the reaction and, if it becomes self-sustaining (and no longer requires an external heat source), combustion develops very quickly and there is a dramatic increase in temperature.
- **Fire growth** - the fire may spread through:
  - Direct burning.
  - Typical mechanisms of heat transmission (convection, conduction or radiation).

The rate, scale and pattern of growth depend on a number of factors, such as:

- Nature, form and amount of fuel.
- Availability of oxygen (open, ventilated versus sealed containment).
- Amount of heat produced by the reaction.

- **Steady state** - the temperature stabilises and the combustion process reaches a steady state (the reaction between the fuel and oxygen is balanced until all the fuel is consumed).
- **Decay** - begins when either the fuel or oxygen has been consumed; the fire will then extinguish and gradually cool down.

TOPIC FOCUS

The three basic stages of the combustion process are:

INDUCTION

- Early stages, evidence of combustion starting.
- May be slow process, smouldering.

FIRE GROWTH

- Rapid development of fire as burning materials act as ignition.
- Level of burning and growth depend on levels of oxygen and fuel present.
- Large volumes of smoke and heat generated and possibly spontaneous combustion.
- Growth rate and temperature will eventually reach a plateau.

DECAY

- Room starved of oxygen and fuel.
- Heat output decreases and fire dies down.

Factors that Influence Fire Growth Rates and Smoke Movement

There are also specific factors that influence fire growth rates and smoke movement related to the structure and contents of the particular building:

- **Building design** - where smoke generated from a fire may:
  - Escape through gaps in doorways, ceilings and walls.
  - Spread:
    - Through vents, lift shafts, staircases, ducts and ceiling voids.
    - Horizontally by convective currents under the ceiling.
    - Vertically between storeys by convective transfer of hot gases and smoke.
- **Insulated core panels** (containing fire-rated rigid urethane insulation) - in some cases the insulation material used gives off toxic gases when heated and, when the foam insulation degrades, causes a collapse of the panel.
- **Internal linings** - materials on the surfaces of walls and ceilings significantly affect the spread of fire and its rate of growth:
  - Particularly the potential for fire spread on internal linings in escape routes (rapid fire spread could prevent occupants from escaping).
  - Materials used should reduce the potential for the development of fire and smoke from the surfaces of walls and ceilings.

TOPIC FOCUS

Spread of fire and its rate of growth on the surface of walls and ceilings:

- Properties of lining materials that might **increase** the risk of fire spread and its growth:
  - Ignitability.
  - Rate of surface flame spread and heat release.
  - Amount of smoke produced when ignited.
  - Tendency to produce flaming droplets.
- Properties that lining materials should have to limit the spread of fire and maximise the time available for escape:
  - Resistance to ignition.
  - Low rate of surface flame spread and heat release limiting:
    - Spread of fire.
    - Production of smoke.
    - Rate of fire growth.

  Examples of such materials include:
  - Exposed brickwork.
  - Exposed blockwork.
  - Mineral fibre board.
  - Woodwool slabs.
  - Plasterboard and skim.
  - Intumescent linings.
  - Concrete, stone or ceramic tiles.

DEFINITION

INTUMESCENT LINING

A material that expands when heated to form an insulating fire-retardant barrier that protects the underlying surface.

- A building's construction materials have an impact on the potential for, and rate of, fire spread:
  - Concrete:
    - Dehydrates, crumbles and collapses.
    - Surface spalls (the breakdown of surface layers which crumble into small pebble-like pieces in response to high temperatures) at >300°C; this is increased by steel reinforcement.
    - Loses structural integrity on cooling.
  - Steel:
    - Expands.
    - Conducts heat.
    - Loses strength and deforms as temperature increases.
    - Changes properties on cooling.

- Brickwork:
  - Fired clay bricks exhibit better fire resistance.
- Timber:
  - Combustible and will be consumed and generate smoke in fire.
  - Burns in a predictable way and its fire resistance can be improved by increasing thickness, selection of fire-resistant varieties (dense wood is better) and surface treatment.
- Plastics:
  - Thermo-setting plastics do not melt but decompose, generating smoke and fumes.
  - Thermoplastics melt, drip and flow in a fire and generate smoke and fumes.
- Glass:
  - Generally offers little resistance to fire (but some specific fire-resisting laminated glasses can provide fire resistance of up to 90 minutes).
- Thermal insulating materials in concealed areas:
  - Most modern varieties are non-combustible.
  - Some older buildings used combustible materials (e.g. sawdust).
- Lime-based plaster on internal walls:
  - If supported by lathing or expanded metal, has good fire resistance.
- Paints:
  - Most are combustible and will aid surface spread of fire (but there are also flame-retardant paints and paints that bubble up to protect the timber beneath).

- Ventilation levels determine the oxygen supply to a fire in an enclosed space and, if air is not replenished, the fire will decay. The level may be a combination of:
  - Natural ventilation (through doors, windows and other openings).
  - Forced ventilation (through mechanical air-handling systems).
- Contents of the premises might typically include:
  - Paper (wallpaper, books, magazines) - will burn in a fire and aid fire spread.
  - Plastics (wall and ceiling linings (expanded foam types), window frames) - some types are self-extinguishing (e.g. unplasticised PVC) and others smoulder, drip and burn.
  - Fabrics and furnishings (seating, curtains and other textiles) - natural fabrics tend to smoulder, while synthetic fabrics (mainly thermoplastics) shrink, melt and ignite.

The Conditions in which Flashover and Backdraught May Occur

These two important phenomena increase the risk in a fire situation:

- A flashover occurs when all the combustible material in an enclosed area simultaneously ignites due to heat build-up to above its auto ignition temperature (typically around 500°C).
- A backdraught occurs when air is introduced into a fire which is decaying through oxygen starvation, causing a rapid and explosive re-combustion.

TOPIC FOCUS

A flashover may occur when:

- A fire is free burning in a room.
- There is a good supply of oxygen from the large size of the room or from a ventilation source.
- The fire generates a high level of radiated heat which is absorbed by other materials in the room, including unburnt gases.
- Materials and gases reach their spontaneous ignition temperatures and ignite even though they are not in direct contact with the flame.

The effect is that the fire has 'flashed' from one side of the room to the other.

STUDY QUESTIONS

1. What is the fire triangle. Your answer should include a fully labelled sketch or diagram.
2. What are the conditions required for combustion to be maintained.
3. What are the basic stages of combustion?
4. What is an exothermic reaction?
5. Outline the main factors that influence the rate of fire growth.
6. Outline the ways in which fire can spread within buildings.
7. Outline the main differences between fires under free burning conditions and fires in enclosed conditions.

(Suggested Answers are at the end.)