2. Fire Protection – Basic Principles

2.1 Oxidation – Combustion – Fire

The chemical process by which a combustible substance combines with oxygen with release of heat to form a new substance, the oxide, is called oxidation.

A rapidly-proceeding oxidation with the appearance of light is called combustion; the light, flame and heat created during combustion are called the fire.

2.2 Combustion process

Combustion always depends on four preconditions which must coincide:

1. There must be a combustible substance,
2. oxygen must have unimpeded access,
3. the ignition temperature of the combustible substance must be attained or exceeded, and
4. the proportion of ingredients necessary for the compound of the combustible substance with the oxygen must be attained.

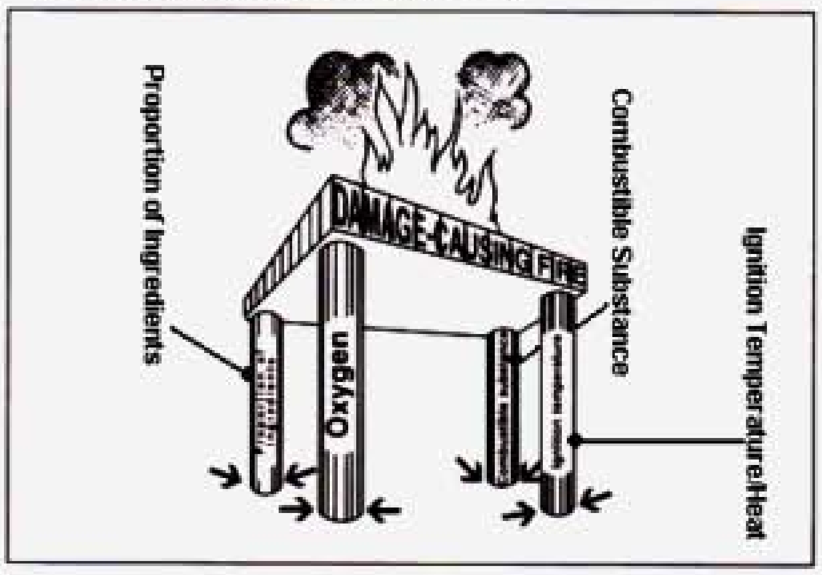


Fig. 2.1 Four-column-model

2.2.1 Combustible substances

Combustible substances are solids, liquids and gases (including vapours, mists, dust) which mixed or in contact with the oxygen contained in the air can be made to burn. For the assessment of the fire risk posed by a substance, the following properties are of importance: ignitability, combustibility, heat of combustion and combustion temperature.

For fire protection on board it is sufficient to know that there are substances which are difficult, normal and easy to ignite. Even just a flying spark can set on fire a substance easy to ignite. Normally-ignitable substances need the heat of combustion of a match to set them alight. Substances difficult to ignite must be strongly heated, e.g. with a blowlamp, before they can be ignited.

The characteristics of combustibility, heat of combustion and combustion temperature are of no significance for the practical side of fire protection on board.

2.2.2 Oxygen

Oxygen is one of the most frequently occurring elements of our living-zone on earth. The air contains about 21% by volume of free oxygen. Chemically combined oxygen is present in water (89% by mass) and in the crust of the earth (50% by mass).

2.2.3 Ignition temperature

Combustible solid or liquid substances cannot by themselves combine with oxygen with the appearance of fire. They do not burn by themselves. Ignition only becomes possible when the combustible substance has been heated to generate gas or vapour and these have mixed with oxygen.

Combustion is always initiated by ignition. It occurs when a combustible substance in contact with an adequate amount of oxygen is heated to a certain minimum temperature, the ignition temperature.

The ignition temperature of a combustible substance is the minimum temperature at which in the presence of oxygen in a proportion which permits ignition fire will appear.

The lowest temperature at which external ignition can generate fire symptoms is called ignition point for solids, flash point for liquids. If the source of ignition is removed, the fire extinguishes again.

The lowest temperature at which positive ignition can generate a fire which remains alight after the source of ignition has been removed is called minimum combustion temperature for solids and fire point for liquids.

The ignitability of a combustible solid is described by its ignition point and its minimum combustion temperature.

The ignitability of a combustible liquid is determined by its flash point and its fire point.

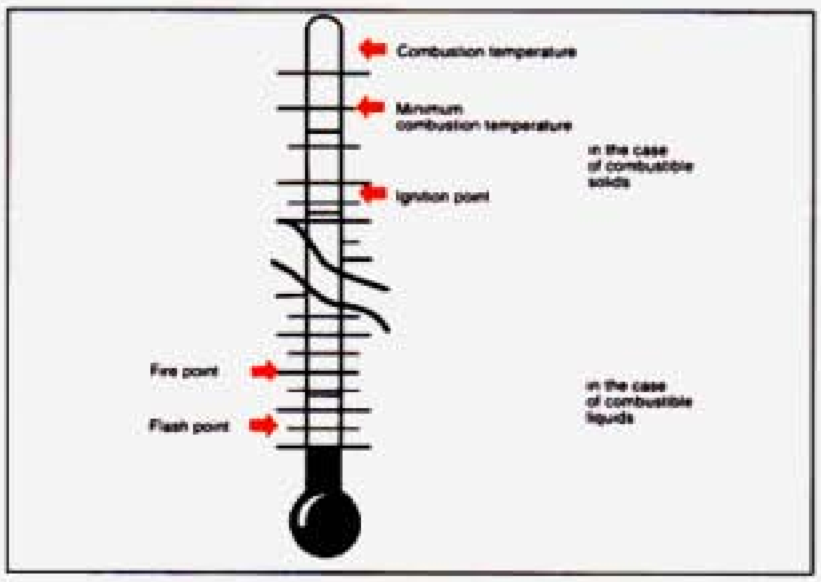


Fig. 2.2 Ignition temperatures

If a combustible substance is heated above its minimum combustion temperature or its fire point, spontaneous combustion can occur.

2.2.4 Flammability ranges – Proportions of ingredients

The chemical compound of a combustible substance with oxygen can only occur if the ingredients are present in specific proportions.

The minimum necessary percentual proportion of the combustible substances in atmospheric air is called the lower flammability limit (explosion limit). The maximum permissible percentual proportion of the combustible substance in atmospheric air, the upper flammability limit (explosion limit). The range between the two limits is called the flammability range (explosion range).

Ignition cannot occur, and combustion is therefore impossible, outside the flammability range.

2.2.5 Forms in which fire appears

Depending on the character of the combustible substance, the fire can appear in two forms, as flames or as a glow. Both forms can occur together or separately.

As flame is described the visible part of a stream of gas comprising three parts. These are:

- the incoming flow in which the combustion air flows to the reaction zone;
- the reaction zone in which the combustible gas released from the combustible solid or liquid by heating rises, mixes with the air and chemically compounds with the oxygen in the air with the generation of light and the release of heat;
- the waste gas flow in which the gaseous products of combustion mixed with air rise and cool further.

What is called glow is the light radiation of a solid heated to a high temperature. The colour of the light radiated allows the temperature to be deduced. Corresponding values are:

Grey glow	400 °C
dark red glow	525 °C
red glow	800 °C
yellow glow	1100 °C
incipient white glow	1300 °C
full white glow	1500 °C

Substances burning with flames only are:

- gases;
- liquids following transition into the vapour form;
- solids which generate vapour or gas when heated.

Substances burning with a glow only are:

- solids which have been de-gassed such as coke or charcoal;
- combustible metals.

Substances burning with flames and a glow are:

- solids which on heating break down into gaseous components and solid carbon.

  The gaseous components form the flames, the solid gives off the glow.

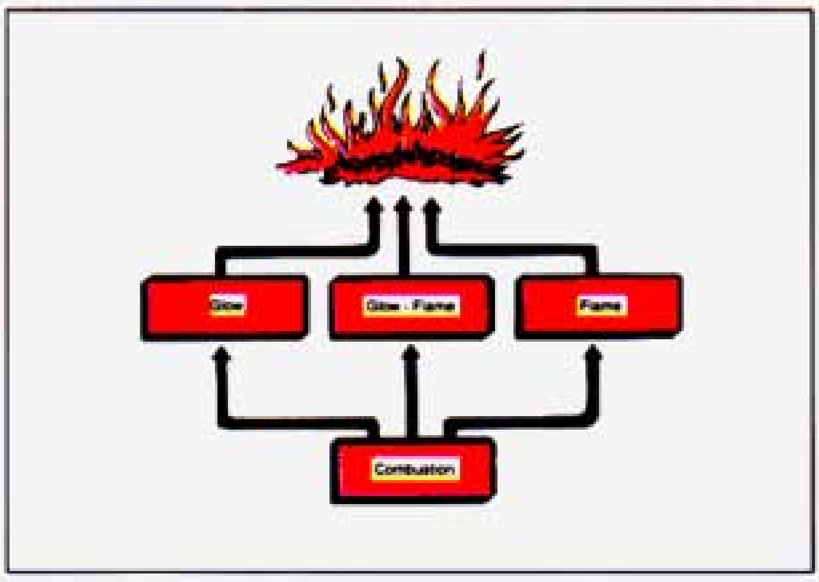


Fig. 2.3 Forms in which fire appears

2.3 Deflagration – Explosion – Detonation

Particularly favourable conditions for combustion prevail if combustible substance and oxygen are present in the correct proportions and additionally the substance is mixed in extremely finely divided form with oxygen. The result is rapidly proceeding combustion.

In deflagration the above-mentioned conditions are not fulfilled, and combustion is incomplete with a low level of pressure and noise, e.g. if gas- or vapour-air mixtures are ignited near the limits of the flammability range.

An explosion is combustion with the creation of strong pressure, heat and light effects. Ignition progresses rapidly, e.g. when petrol vapours explode, at about 20 m/sec.

If the ignition propagation rate becomes supersonic, it is called a detonation. Here a pressure wave is generated, producing heat of compression at the wave-front which causes ignition. The detonation pressures can be up to 150,000 bar and the ignition propagation rate over 6 km/sec (TNT instantaneous fuse).

The ignition propagation rates are in the case of:

- deflagrations, of the order of magnitude of cm/sec;
- explosions, of the order of magnitude of m/sec;
- detonations, of the order of magnitude of km/sec.

2.4 Heat
Heat Transfer – Heat accumulation – Spontaneous combustion

Heat is a form of energy. It is generated during combustion by conversion of the chemical energy of the combustible substance by means of the oxygen in the air, as heat of combustion.

Heat acts physically by way of:

- thermal expansion;
- change of state of aggregation;
- alteration of the strength properties.

Of these effects, on board seagoing ships the alteration of strength has the most serious consequences. Shipbuilding steels if heated to 500 °C lose up to 50% of their strength and do not recover it when they cool. Steel parts affected by fire must therefore be replaced.

Heat can be transferred from one substance to another, e.g. from an ignition source to a combustible substance.

There are three forms of heat transfer:

Heat behaviourion is the transfer of heat in a solid, liquid or gaseous substance between immediately adjacent particles. Gaseous substances behaviour heat badly, liquid ones well. Amongst solids there are good and poor behaviourors of heat. Good behaviourors are for instance metals such as steel, iron, copper, light alloys; poor behaviourors are for instance wood, concrete, wool, rubber, leather.

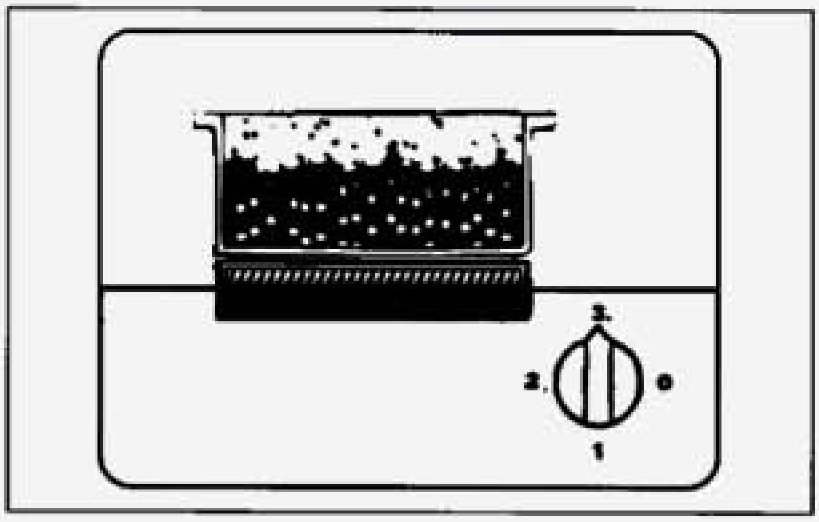


Fig. 2.4 Example of heat behaviourion

Heat radiation is the radiation emitted by a substance, surrendering a part of its thermal energy to its environment, as a consequence of its temperature. It penetrates open space even against the wind and can travel substantial distances. In the case of major fires, ignition due to heat radiation has been observed even at a distance even of 40 m.

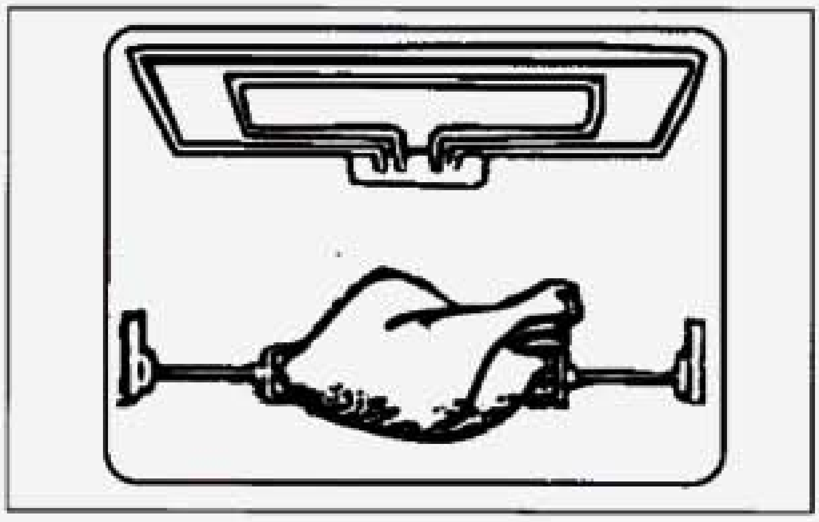


Fig. 2.5 Example of heat radiation

Heat convection is the transfer of heat carried by a liquid or gaseous substance. It is utilised for instance in space heating using hot-water heating elements.

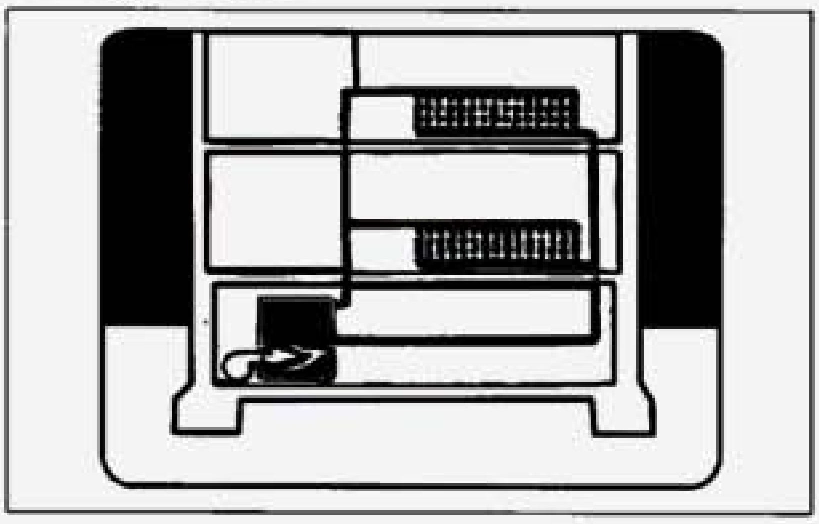


Fig. 2.6 Example of heat convection

Heat accumulation

If more heat is supplied or generated than is used or removed, there is a heat accumulation. As the cause of spontaneous combustion this is of crucial importance.

Spontaneous combustion

If a combustible substance oxidises slowly, i.e. without flames appearing, and the heat generated in the process accumulation, the temperature inevitably rises with increasing speed as a result of this accumulation until the ignition temperature is reached. Spontaneous combustion then follows.

Spontaneous combustion is assisted by the following circumstances:

- high ambient temperatures, e.g. when loading bag cargo in tropical ports (expeller, fish meal, etc);
- fine granulation or large surface areas of combustible substances, such as rich coal, greasy cotton, cleaning rags;
- heat-generating bacteria decomposing organic substances, such as in fermenting hay or moist fish meal;
- high oxygen concentrations, e.g. at the reaction between oxygen carriers such as alkali peroxides with water and combustible

substances such as organic dust, paper, wood, also called cargo hold sweepings.

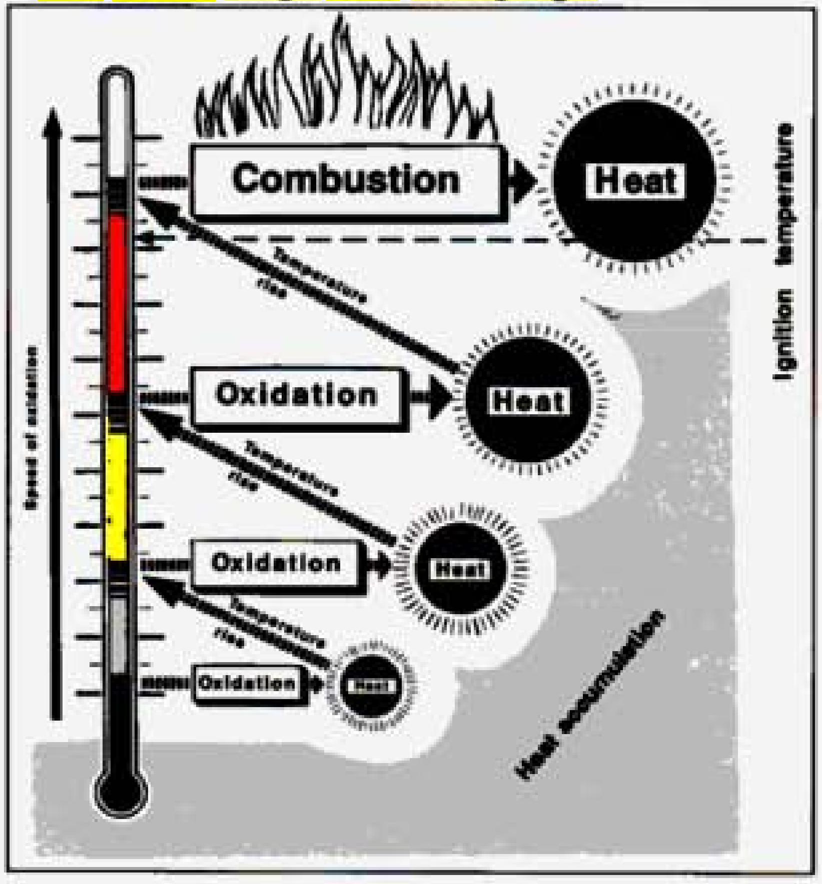


Fig. 2.7 Spontaneous combustion

A schematic representation of the spontaneous combustion process (The process is shown here in fairly large steps to make it easier to understand. In reality it progresses steadily. As a factor, the speed of oxidation doubles for every rise in temperature of 10 °C, in accordance with van't Hoff's Law).

2.5 Classes of fires

The object of subdivision into classes of fires is the appropriate allocation of extinction methods and means to the various combustible substances.

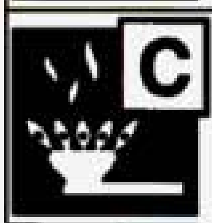
Classification of fires according to EN 2 and DIN 14 406	
	Fires involving solids, mainly organic materials, which normally form a glowing mass when burning; e.g. wood, paper, straw, coal, textiles, car tyres.
	Fires involving liquids, or substances which become liquid; e.g. petrol, oils, greases, lacquers/paints, resins, waxes, tar, ether, alcohols, plastics.
	Fires involving gases; e.g. methane, propane, hydrogen, acethylene, town gas.
	Fires involving metals; e.g. aluminium, magnesium, lithium, sodium, potassium and their alloys.

Fig. 2.8 Classes of fires

2.6 Small – Medium – Large Fire

Fires are subdivided into three classes according to their extent:

A small fire is one of limited extent, contained within an enclosed compartment in the accommodation, culinary/service or cargo areas;

A medium fire is one extending out to involve directly adjacent compartments, e.g. to adjacent cabins in the accommodation area or from a container to adjacent ones. Any fire in the machinery spaces in which combustible liquids like fuel or lube oil escaping under pressure are burning is a medium fire;

A large fire exceeds a medium one in extent and involves several areas of the ship, e.g. machinery plus accommodation area or machinery plus cargo area. Also designated major fires are ones which totally engulf an area of the ship, e.g. several decks of the accommodation spaces.

2.7 Materials

In practice a distinction is made between combustible and noncombustible materials.

An "noncombustible material" is one which does not release ignitable gas or vapour in such quantities that when heated to 750 °C the gas/vapour can ignite spontaneously.

Every other material is combustible material.

Some combustible materials can be made hard to ignite by treatment with fire-resistant substances.

"Low flame-spread materials" are materials, woven textiles or coatings which are able to prevent the spread of a fire or restrict it adequately.

2.8 Preventive fire protection

By structural fire protection measures, the start of a fire is impeded, its spread substantially prevented and fire fighting facilitated.

Structural fire protection includes design/construction measures such as the subdivision into main fire sections, the arrangement and design of doors, fire flaps and other closures, escape- and rescue routes, the use of noncombustible or low flame-spread materials, the installation of fire alarm and extinguishing systems and appliances, and of special equipment to protect for example compartments or installations in which combustible liquids, compressed gases or dangerous substances are used, transported or stored, such as fuel tanks, pumps or pipelines.

Operational fire protection results in timely recognition of fire risks and safe operating of fire protection equipment. Operational fire protection includes above all the organisation of operations so as to prevent fire risks arising.