Fires and Extinguishing Media

Learning Outcome
When you complete this module you will be able to:

Describe the fire classifications and the types of extinguishing media suitable for each classification.

Learning Objectives
Here is what you will be able to do when you complete each objective:

1. Describe the theory and terminology of fires.
2. Discuss the life safety issues associated with fires.
3. Explain the four classes of fires.
4. Describe the types of fire extinguishing media and how they act on fires.
DEFINITIONS

As with any topic there are certain definitions that must be understood before one can truly study and understand the subject.

Combustion

Combustion is defined as an exothermic, self-sustaining reaction involving a solid, liquid and/or gas-phase fuel. The process is usually associated with the oxidation of a fuel with the emission of light. Combustion can occur in inert atmospheres.

Oxidizing Agents

An oxidizing agent is a chemical substance that can react with hydrogen or with metals. Often the term oxidizing agent is used to refer to any chemical element or compound that could combine with a fuel in the combustion process.

Oxygen is the simplest and most common oxidizing agent; however the term includes many other chemicals. The following are examples of oxidizing agents:

1. Oxygen and ozone.
2. Hydrogen peroxide.
3. Members of the halogen group such as fluorine, chlorine, bromine, and iodine.
4. Concentrated nitric and sulphuric acids.
5. Oxides of heavy metals such as manganese dioxide, and lead oxide.
6. Nitrates, chlorates, perchlorates, and peroxides.
7. Chromates, dichromates, permanganates, hypochlorites, and hypobromites.

Most accidental fires involve a reaction with the primary oxidizing agent, air. Atmospheric air is about 21% oxygen by volume. The balance is mainly nitrogen which plays no part in the combustion process.

Reducing Agents (Fuels)

Substances known as reducing agents in chemical terms are involved as fuels in the combustion process, i.e. these are the substances that will combine with an oxidizing agent.
The most common materials involved as fuels in fires are:

1. Carbon.
2. Carbon monoxide.
3. Compounds rich in carbon and hydrogen.
4. Readily oxidizable nonmetals such as sulphur and phosphorous.
5. Substances which contain cellulose such as wood and natural textiles.
6. Metals such as aluminum, magnesium, titanium, zirconium, and the alkali metals such as sodium and potassium.

Materials high in carbon and hydrogen content (hydrocarbons) are common fuels. Such materials are also the most flammable. Methane, butane, propane, fuel oils, and gasoline are common examples of hydrocarbon fuels.

**Temperature**

Temperature is a measure of the molecular activity occurring within a substance. Oxidizing reactions result in heat being generated which in turn increases the molecular activity. This causes fires to endure and renew themselves due to the increase in intensity of the interactions between fuels and oxidizing agents.

**Uninhibited Chain Reactions**

These reactions are uncontrolled molecular activity. They result from the interaction of the molecules in the fuel and oxidizing agents. The interaction provides the necessary energy to sustain the combustion process.

**FIRE THEORY**

Although the combustion process is very complex, and in many cases is not fully understood, we do know that combustion occurs in two basic modes; flaming, and flameless surface (glowing) combustion. These two modes can occur either singly or in combination.

Examples of fuels that burn in both modes are coal, sugars, starches, wood, straw and other similar vegetable materials, and thermosetting plastics which do not melt.
Flaming Combustion

A fire characterized by flame is the most common. It should be noted that there cannot be a flaming fire unless a vapor is burning. This is true whether the vapor already exists, or is evaporated, distilled, or driven off from a solid or a liquid. This mode is usually associated with relatively high burning rates.

A requirement for flaming combustion to occur is the occurrence of uninhibited chain reactions. If they are inhibited or interrupted, flame continuity ceases and the flaming combustion reaction is suppressed. This will result in the fire being extinguished.

Flammable liquids and gases burn in the flaming mode only.

![Fire Tetrahedron](AH_1_0_1.bmp)

Figure 1
Fire Tetrahedron

Although the actual reactions and process are very complex, it is possible to represent the requirements for flaming combustion in a simple manner. Referring to Fig. 1, the requirements of the flaming mode can be represented as a tetrahedron (“four faces”). Each of the four sides is in direct contact with the other three (pyramid shape). Each side represents one of the four basic requirements for flaming combustion: fuel, temperature, oxygen, and an uninhibited chain reaction.

Flameless Surface (Glowing) Combustion

The glowing fire is characterized by the absence of flame, and the presence of extremely hot material at the surface where the combustion is taking place. This mode of combustion occurs only with solid fuels.
Fig. 2 represents the flameless glowing type of combustion in the form of a triangle. Each side represents one of the three basic requirements for this mode of combustion: fuel, temperature, and oxygen.

Carbon, the readily oxidizable metals (such as magnesium, aluminum, and uranium), and nonmetals (such as phosphorous) are examples of materials that burn in the flameless glowing surface mode.

Solid fuels often burn as predominantly flaming fires, but can also be of the flameless glowing type as well. Frequently the solid decomposes to give off a vapor, initially burns with a flame, and subsequently burns in the flameless mode. An example would be wood, which initially burns with flame from the vapors formed as it decomposes. The charcoal which is formed will continue the combustion process in the glowing mode.

Conclusion

Both modes of fire involve three essential elements: fuel, oxidizing agents (usually oxygen from the air), and a temperature high enough for the reaction to proceed (heat). In addition, the flaming mode of combustion also involves uninhibited chain reactions (collision of molecules to sustain flame continuity). In each mode all of the basic requirements must exist for the fire to start and be sustained.

In most cases, flaming combustion will cease if the oxygen concentration is lowered to less than 15% for hydrocarbon gases. Wood will continue to burn in the flameless glow mode with oxygen levels as low as 5%.

Removal of any one of the three (flameless), or four (flaming) basic requirements will provide a means of extinguishing a fire.
LIFE SAFETY

The threat to life from a fire comes not only from the high temperatures, but from the gaseous products of combustion, and the depletion of oxygen in the vicinity of the fire.

It should be noted that at an oxygen concentration of about 17% a person’s motor coordination is impaired; in the range of 10 to 14% an individual will still be conscious but will fatigue easily and show impaired judgement. Below a concentration of about 10% an individual will lose consciousness and will quickly need fresh air or oxygen to revive. These percentages will be higher if the individual has an increased oxygen demand due to exertion.

Some combustion products act basically as asphyxiants; i.e. they reduce the concentration of oxygen in the air. Other combustion products are toxic, and/or irritants.

In all cases, a person’s judgement and/or ability to deal with the situation is likely to be hampered.

CLASSES OF FIRE

Different types of fire need different types of extinguishing agent. The National Fire Protection Association Extinguisher Standard classifies fires into four categories.

Class A

Fires in ordinary combustible materials (such as wood, cloth, paper, rubber, and many plastics) which are extinguished by the heat absorbing (cooling) effect of water or water solutions, the coating effect of certain dry chemicals which retard combustion, or the interruption of the combustion chain reaction by halogenated agents.

Class B

Fires in flammable or combustible liquids, flammable gases, greases, and similar materials, which must be put out by: excluding air (oxygen), inhibiting the release of combustible vapors, or interrupting the combustion chain reaction.
Class C

Fires in live electrical equipment, where safety to the operator requires the use of electrically nonconductive extinguishing agents. (Note: When electrical equipment is de-energized, extinguishers for Class A or Class B fires may be used.)

Class D

Fires in certain combustible metals (such as magnesium, titanium, zirconium, sodium, potassium, etc.) which require a heat-absorbing extinguishing medium that does not react with the burning metals.

EXTINGUISHING MEDIA

The means of extinguishing a fire can be summarized into four categories; cooling, reduction in oxygen content, removal of fuel, and chemical flame inhibition (for flaming fires). Fuel removal refers not only to the physical removal of the fuel, but also to the cutting off of fuel vapors from combustion (flaming mode), or the covering of the glowing surface (flameless mode) to isolate the fuel from the oxidizing agent.

The various broad classes of extinguishing media available use one or more of these methods to extinguish a fire.

Water

Water is an efficient and commonly available extinguishing agent. Water extinguishes by cooling the combustible material and lowering its temperature to a point where combustion is no longer sustained. The water may also produce steam, which will dilute the ambient oxygen supply.

Carbon Dioxide

Carbon dioxide is noncombustible, and does not react with most substances. As a gas it can penetrate the fire area and leaves no residue to be subsequently cleaned up.

Carbon dioxide primarily extinguishes by reducing the oxygen content of the atmosphere to a point where combustion can no longer be supported. The CO\textsubscript{2} displaces the O\textsubscript{2} that is required for combustion. Under some conditions of application, the available cooling effect is helpful, especially where the CO\textsubscript{2} is applied directly to the burning material. The principal advantage of CO\textsubscript{2} is that it does not leave a residue. This consideration is important in laboratories, areas where food is prepared, and where there is electronic equipment.
Dry Chemicals

Dry chemical extinguishing agents are either regular or multipurpose.

The regular or ordinary dry chemicals are used for Class B fires (flammable liquids) and for Class C fires (electrical equipment). The multipurpose dry chemicals can also be used on Class A fires (ordinary combustibles) as well as Classes B and C.

The term “Dry Chemical” should not be confused with the term “Dry Powder” which relates to compounds used for Class D fires (combustible metals).

When dry chemical agents are introduced directly into the fire area, extinguishment of the flame is almost instantaneous. Smothering, cooling, and radiation shielding contribute to the extinguishing mechanism. The principal mechanism in a flaming mode fire is considered to be a chemical chain breaking reaction in the flame. In a flameless surface fire the extinguishment is achieved by removing the fuel from the fire with the coating action of the chemicals.

Dry chemicals should not be used where delicate electrical contacts, relays, and switches are present. The chemicals have an insulating property and some are corrosive. Due to the corrosive nature, dry chemicals should be removed from undamaged surfaces as soon as possible after fire extinguishment.

Halogenated Agents

Halogenated extinguishing agents (commonly referred to as Halons) have been developed by substituting fluorine, chlorine, bromine, and/or iodine for one or more of the hydrogen atoms in either methane or ethane. This substitution makes the resulting compounds nonflammable and gives them excellent flame extinguishment properties.

The nomenclature used for the Halons is intended to provide a simple unique method of identifying the compound without the complexity of chemical names. This is achieved by using a three to five digit number after the name Halon. The first digit gives the number of carbon atoms in the molecule, the second gives the number of fluorine atoms, the third the number of chlorine atoms, the fourth the number of bromine atoms, and, if present, the fifth gives the number of iodine atoms. For example:

Halon 104 has 1 carbon and 4 chlorine atoms in the molecule. This is carbon tetrachloride, an early “Halon” no longer used.

Halon 1301 has 1 carbon, 3 fluorine, and 1 bromine atom in the molecule.
Halon 1211 has 1 carbon, 2 fluorine, 1 chlorine, and 1 bromine atom in the molecule.

Halon 2402 has 2 carbon, 4 fluorine, and 2 bromine atoms in the molecule.

The first three Halons illustrated above are derived from methane, and the fourth is derived from ethane. While Halon 2402 is a highly effective extinguishing agent, its toxicity limits its use.

The presence of bromine in the Halon molecule greatly enhances the fire extinguishing ability; however it also increases the toxicity of the Halon and its decomposition products.

The effects of the halogens in the “Halon” molecule are as follow:

Fluorine: Increases the thermal stability, and reduces the boiling point and toxicity.

Chlorine: Provides a fire extinguishing ability; but reduces the thermal stability of the molecule, and increases the boiling point and toxicity of the substance.

Bromine: Provides essentially the same effects as chlorine, but to a greater extent.

The extinguishing mechanism of the Halons is not clearly understood; however, it is believed that a chemical reaction takes place which interferes with the uninhibited chain reaction that occurs in the flaming mode of the combustion process.

All halogens are active in “chain breaking” in the combustion process; however bromine is much more effective than fluorine or chlorine.

Halons are stored as liquids and discharged as gases.

Halons do not leave any residue and are often used to protect electrical and electronic equipment. They are also used in air and ground vehicle engine compartments where speed of extinguishment is essential. The clean up of equipment after Halon use is minimal.
Some situations where Halons are effective and might be useful are:

1. Where a clean extinguishing agent is required.
2. Where live electrical or electronic equipment is present.
3. Where flammable liquids or gases are present.
4. Where the speed of extinguishment is essential (e.g. Halon 2402 in aircraft engine compartments).
5. Where the area is normally occupied by personnel (Halon 1301).

Halons are ineffective for extinguishing fires involving:

1. Fuels that contain their own oxidizing agent.
2. Reactive metals.
3. Metal hydrides.
4. Chemicals capable of autothermal decomposition.

It should be noted that, at the date of printing of this module, the use of Halons is being discouraged due to concerns about the environmental impact of halogenated hydrocarbons.

**Aqueous Film-Forming Foam (AFFF)**

This extinguishing agent is an aqueous film-forming surfactant in water. A surfactant is a substance introduced into a liquid to increase its spreading and wetting qualities. Many detergents are surfactants.

The AFFF agents form an airfoam and in addition can form a water solution film on the surface of flammable liquids. The aqueous layer of solution under the foam maintains a floating film on hydrocarbon fuel surfaces which helps to suppress combustible vapors and cools the underlying layer of hydrocarbon fuel.

The extinguishing action of AFFF is to exclude air, to cool, and to provide a seal for the vapors from the hydrocarbon.

AFFF is suitable for Class A and B fires. On Class A fires the foam acts as a coolant and a penetrant to reduce the temperature below the ignition level. On Class B fires the foam acts as a barrier to exclude air or oxygen from the fuel surface. It is not recommended for use on electrical fires (Class C) as it is electrically conductive.
Dry Powder

Dry powder agents are for use on Class D fires (combustible metals).

A variety of metals burn, particularly if in a finely divided form. Some metals burn when exposed to external heat; others burn from contact with moisture, or reaction with other materials.

Dry powders used on combustible metals are often a combination of chemicals determined by the type of combustible metal or metals for which the powder is to be used. The dry powder is spread over the fire and the extinguishing action is by smothering to exclude air and also by cooling.

The agent, extinguisher, and method of application should be chosen in accordance with the manufacturers’ recommendations.

Be aware that the dry powder used must be suitable for the particular combustible metal, and do not confuse dry powder with dry chemicals.
References and Reference Material

For more information on this topic, the following is recommended: