PDHonline Course M110A (4 PDH)

Introduction to Fire Protection Systems

Instructor: Lawrence J. Marchetti, P.E.

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
www.PDHcenter.com

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MODULE - 1
OVERVIEW OF THE COMBUSTION PROCESS

In this module, we will introduce the following concepts:

- Definition of fire
- Classes of fires.
- Concept of fire tetrahedron
- Concept of pyrolysis.
- Stages of a Fire
- Discussion of explosions.

Following successful completion of this module, the student should be able to:

- Define the combustion process
- Name the (5) classes of fires
- Understand the concept of the fire tetrahedron
- Have a fundamental understanding of pyrolysis
- Have a fundamental understanding of the theory of explosions.

Before we can introduce the fundamentals of fire protection systems, we must first examine the process of combustion (fire). Unfortunately, it is impossible in this introductory course to completely describe all the complex chemical and physical reactions that take place during a fire. However, this section of the course will attempt to introduce the student to the fundamental theories of fire and explosion.

FIRE TETRAHEDRON

For many years the concept of fire was based upon the fire triangle: fuel-heat-oxygen. Further fire research determined that a fourth element, a chain reaction, was a necessary component of fire. The fire triangle was revised to the fire tetrahedron (pyramid) to reflect this fourth element. Essentially, all four elements must be present for fire to occur: fuel, heat, oxygen, and a chain reaction. Removal of any one of these essential ingredients from this mix will result in fire extinguishment.

THE COMBUSTION PROCESS (FIRE)

The generally accepted definition of combustion (fire) is ***a process involving <u>rapid</u> oxidation at elevated temperatures accompanied by the evolution of heated gaseous products of combustion, and the emission of visible and invisible radiation***. Oxidation occurs all around us in the form of rust on metal surfaces, and in our bodies by metabolizing the food we eat. However, the key word that sets combustion apart from other forms of oxidation is the word "rapid".

The combustion process is usually associated with the oxidation of a fuel with the emission of light in the presence of an oxidizer (oxygen). Oxidation, in the strict chemical sense, means the loss of electrons. For an oxidation reaction to occur, a reducing agent (fuel), and an oxidizing agent (usually oxygen) must be present. As heat is added (ignition source), the reducing agent (fuel) molecules and oxidizing agent (oxygen) molecules gain energy and become active. This molecular energy is transferred to other fuel and oxygen molecules (chain reaction). A reaction takes place where the reducing agent (fuel) looses electrons and the oxidizing agent (oxygen) gains electrons. This exothermic electron transfer emits heat and/or light. Controlled we refer to this process as combustion (e.g. furnace combustion), and uncontrolled we refer to this process as fire (e.g. forest fires, structure fires).

There are three generally recognized stages to a fire. The incipient stage, smoldering stage, and flame stage.

<u>The incipient stage</u> is a region where preheating and gasification (slow pyrolysis) are in progress. Gas and sub-micron particles are generated and transported away from the source by diffusion, air movement, and weak convective movement produced by the buoyancy of the pyrolysis products.

<u>The smoldering stage</u> is a region of fully developed pyrolysis that begins with ignition and includes the initial stage of combustion. Invisible aerosol and visible smoke particles are generated and transported away from the source by moderate convection patterns and background air movement.

The flaming stage is a region of rapid reaction that covers the period of initial occurrence of flame to a fully developed fire. Heat transfer from the fire occurs predomanently from radiation and convection from the flame.

The combustion process occurs in two modes:

- The flaming mode
- The flameless surface mode (smoldering or glowing embers).

For the flaming mode of combustion, it is necessary for solid and liquid fuels to be vaporized. The solid fuel vapors are thermally driven off (distilled) and the liquid fuel vapors evaporated. It is this volatile vapor from the solid or liquid fuels that we see actually burning in the flaming mode. This gas or vapor mitigation process (emitted from the fuel) is referred to as **pyrolysis**. Once a flame has been established, heat transfer from the flame to the fuel surface continues to drive off more volatiles and perpetuates the combustion process. For continued burning, the flaming mode requires a high burning rate, and a loss of heat associated with heat transfer from the flame area in the conduction, convection, and radiation modes. If the heat loss is less than the energy output of the fire, the fire will grow. If the heat loss is greater than the energy output of the fire (as in the application of water), the fire will extinguish.

Both modes (flaming and flameless surface modes) can occur singly, or in combination. Flammable liquids and gases only burn in the flaming mode. Wood, straw, and coal are examples where both modes may exist simultaneously.

Flaming combustion can occur in the following forms:

1. Premixed flames where the fuel and oxygen are mixed prior to ignition (e.g. the flame on a Bunsen burner, gas stove, or propane torch).

2. Diffusion flames (more common), where the fuel and oxygen are initially separate but burn in the region where they mix (burning of a pool of flammable liquid or the burning of a log.)

CLASSES OF FIRE

Combustible and flammable fuels involved in fires have been broken down into five (5) categories:

- Class A – fires involving normal combustibles such as trash, wood paper.
- Class B- fires involving most flammable liquids such as gasoline, grease, paint, and include propane and butane.
- Class C- fires involving energized electrical equipment such as transformers, motors, and appliances.
- Class D- fires involving combustible metals such as potassium, sodium, aluminum, and magnesium.
- Class K- Cooking oils, greases, vegetable oils, and animal fats.

To summarize, a fire begins by an external ignition source (heat) in the form of a flame, spark, or hot ember. This external ignition source heats the fuel in the presence of oxygen (oxidizer). As the fuel and oxygen are heated, molecular activity increases. If sufficiently heated, a self-sustaining chain reaction (molecular activity) occurs between the fuel and oxygen that continues the heating process (chain reaction) without the need for the external ignition source. Once ignition has occurred, it will continue until all the available fuel or oxidant has been consumed (removal of fuel or oxygen), or by cooling (removal of heat), or by reducing the number of excited molecules (breaking the chain reaction).

EXPLOSIONS

Generally, an explosion is defined as ***a rapid release of high-pressure gas into the environment***. The energy from this rapid release of the high-pressure gas is dissipated in the form of a shock wave.

Explosions can be classified as physical (a balloon bursting), physical/chemical (boiler explosion), or chemical reaction (combustion of a gas/particle mixture). Our discussion will focus on chemical reaction explosions.

The process of a (chemical reaction) explosion is similar to the combustion process whereby a fuel and oxidant have pre-mixed prior to ignition (e.g. gasoline vapor and air, grain dust and air, etc.). However, in an explosion the oxidation process proceeds at a greatly accelerated rate. The oxidation process is usually (but not always) confined within an enclosure such as a tank, grain silo, etc., so that a rapid high-pressure rise occurs with an associated flame front. Generally, it is this high-pressure shock wave that causes the damaging effects from an explosion.

Resultant shock waves that propagate from the point of ignition at a velocity less than the speed of sound (1130 ft/sec. @ 70° F) are termed ***deflagrations.*** Shock wave velocities in excess of the speed of sound are termed ***detonations.***

A peak overpressure rise of 1 pound per square inch (psig) is sufficient to knock a person down. A 2-3 psig peak overpressure shock wave is sufficient to shatter an 8 to 12-inch thick concrete wall.

Fundamentals of explosion protection systems will be discussed in module 4.