Principles of Fire

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Section I - Firefighting Fundamentals

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Introduction

Fire is a complex chemical reaction that has been harnessed by humans for many years. Many productive applications of fire have been developed such as cooking, heating, and manufacturing. Fire, when not controlled, can be very destructive. As firefighters, you will respond to suppress structure, vehicle, and vegetation fires. During suppression, the firefighter is exposed to the dangerous components of fire, including smoke and heat. Many firefighter injuries and deaths can be attributed to these exposures. Knowledge of basic fire science principles, such as the fire tetrahedron, products of combustion, and phases of fire will prepare the first responder to safely and effectively mitigate a fire.

Fire Science Terminology

Air Entrainment

The process of air or gas being drawn into a fire, plume, or jet.

Auto-Ignition Temperature

The lowest temperature at which a combustible material ignites in air without spark or flame.

Backdraft

An explosion resulting in the sudden introduction of air into a confined space containing oxygen deficient superheated products of incomplete combustion.

British Thermal Unit (BTU)

The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Calorie

The amount of heat necessary to heat one gram of water one degree Celsius.

Combustion

A chemical process of oxidation that occurs at a rate fast enough to produce heat and light in the form of either a glow or flame.

Conduction

Heat transfer to another body or within a body by direct contact.

Convection

Heat transfer by circulation within a medium such as a gas or a liquid.

Endothermic Reaction

A reaction that absorbs heat.

Exothermic Reaction

A reaction that produces heat.

Fire

The rapid oxidation of a fuel producing heat and light.

Fire Point

The temperature to which a liquid must be heated in order to sustain burning after the removal of an ignition source. Typically, only a few degrees higher than the flash point.

Flameover

The condition where unburned fuel from the original fire has accumulated in the ceiling layer to a sufficient concentration that it ignites and burns. Typically precedes Flashover.

Flammable

Capable of burning with a flame.

Flammable Limits

The upper and lower concentration limit of a flammable gas. The UEL is the upper explosive limit, when the fuel/air ratio is too rich to burn. The LEL is the lower explosive limit, when the fuel/air ratio is too lean to burn.

Flash Point

The lowest temperature at which a liquid produces a flammable vapor.

Flashover

Transition stage of a fire where all contents in a compartment reach their ignition temperature by thermal radiation and subsequently ignite, resulting in full room involvement. "Flashover is the transition from a fire in a room, to a room on fire".

Fuel

Any substance that can undergo combustion.

Fuel Controlled Fire

When the size of the fire is controlled by how much fuel is burning

Heat

A form of energy characterized by the vibration of molecules and capable of initiating and supporting chemical changes and changes of state.

Heat release rate (HRR)

The rate at which heat energy is generated by burning

Heat Transfer

The transport of heat energy from one point to another caused by a temperature difference between those points.

Ignition

The process of initiating self sustained combustion.

Oxidation

The process by which a substance combines with oxygen.

Piloted Ignition Temperature

Minimum temperature a substance should attain in order to ignite.

Plume

The column of hot gases, heat, and smoke rising above a fire

Pyrolysis

Process in which a material is decomposed, or broken down into simpler molecular compounds by the effects of heat alone; pyrolysis often precedes combustion.

Radiation

Heat transfer by way of electromagnetic waves.

Smoke

The airborne solid and liquid particulates and gases present when a material undergoes pyrolysis or combustion.

Smoldering

Combustion without flame, usually with incandescence and smoke.

Spontaneous Ignition

Initiation of combustion of a material by an internal chemical or biological reaction that has produced sufficient heat to ignite the material.

Temperature

The degree of heat of a body, as measured by a thermometer or similar instrument. Temperature is typically measured in degrees of Celsius or Fahrenheit.

Thermal Layering

Thermal layering is the stratification of air and fire gases into layers based on their temperatures.

Vapor

The gas phase of a substance.

Ventilation Controlled Fire

A fire in which the growth is controlled by the amount of air available to the fire.

Fire Chemistry

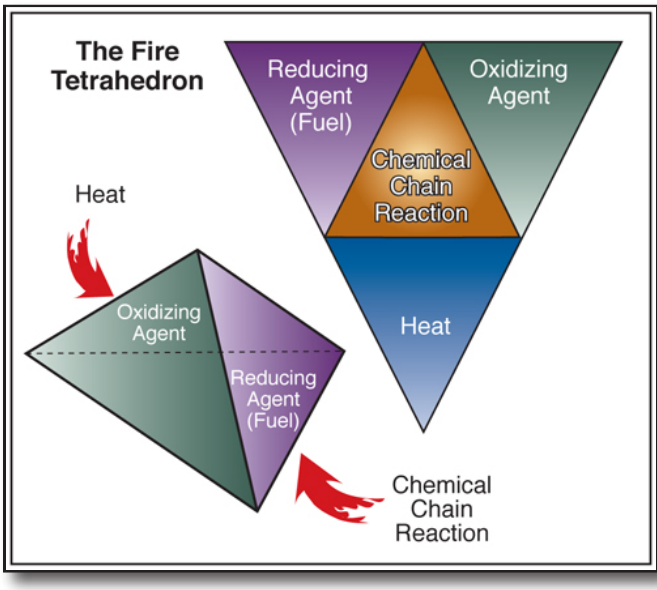

Figure 7-1 Fire Tetrahedron

All matter is composed of elements, or a combination of elements that form compounds. Elements are substances that will not break down into simpler substances. There are 92 natural elements. All elements are composed of smaller units called atoms. Atoms are the smallest unit of an element that can take place in a chemical reaction. In a fire, there are many chemical reactions. Overall, fire is an oxidative reaction. When atoms from a fuel mix with oxygen in the air, it is known as oxidation.

Fire is defined as a rapid oxidation of a fuel producing heat and light.

The Fire Tetrahedron

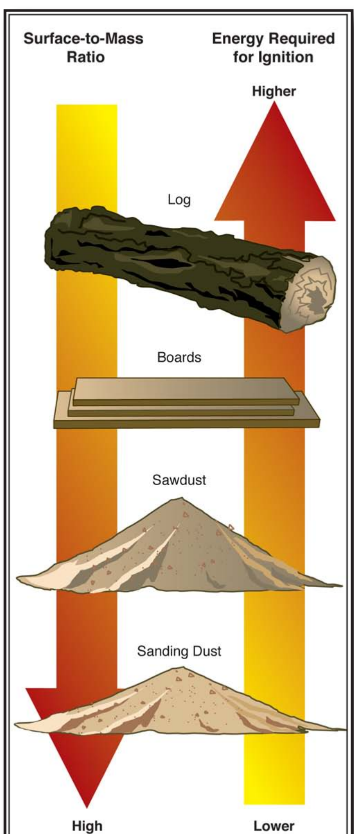

Figure 7-2 Surface : Mass ratio of solid fuel

Four components must be present in order for a fire to occur; fuel, heat, oxygen, and an uninterrupted chemical chain reaction, Figure 7-1. When one of these four components is removed, burning will cease.

Fuel

A fuel is any substance that can undergo combustion. There are two types of fuel; organic and inorganic. Organic fuels typically contain carbon, hydrogen, and oxygen. These fuels include wood, plastics, gasoline, and natural gas. Inorganic fuels typically do not contain carbon and include magnesium and sodium. Fuel exists in three different forms; solids, liquids, and gases. The state of a given material depends on temperature and pressure. Though fuel comes in different forms, ultimately, solids and liquids must be converted into a gaseous state in order for combustion to occur. This chemical changing process is defined as pyrolysis.

Solids

Solid fuels include woods, plastics, cloth, synthetics and metals. A solid must first be heated to a sufficient temperature to pyrolyze. The vapors are then subsequently ignited. Many factors affect the ignitability of a solid. These include the type of solid fuel present, geometry of the solid fuel, surface to mass ratio, Figure 7-2, moisture content, and density. A piece of paper will ignite much easier than a 2x4 piece of wood because of the differences in density and surface to mass ratio.

Liquids

Liquid fuels include gasoline, kerosene, diesel, cooking oil, molten solids, solvents, and thinners. Like solids, liquid fuels must be vaporized, or turned into a gaseous state in order to burn. Factors that affect the ignitability of a liquid include the flash point and fire point. A liquid fuel's flash point is the temperature at which it will give off enough vapors to ignite but not sustain combustion. Fire point is the temperature at which a liquid will give off enough vapors to ignite and sustain combustion.

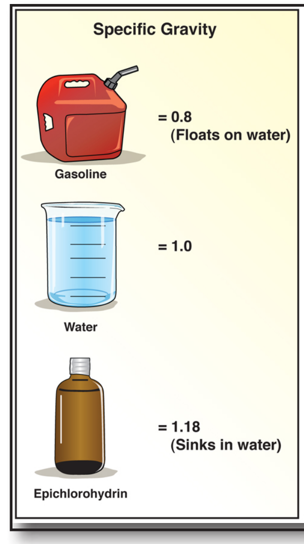

Figure 7-3 Specific Gravity of Liquid

Ignitable liquids can be classified as either flammable or combustible. A liquid with a flash point below 100° F is classified as a flammable liquid. Gasoline has a flash point of -45 degrees F. Liquids with a flash point of 100° F or above are classifies as combustible liquids. Kerosene and lighter fluid are examples of combustible liquids.

Liquids have no definite shape and will assume the shape of their container. The weight of a liquid as compared to the weight of water is known as its specific gravity. Water has a specific gravity of 1.0. Liquids that will not mix with water and have a specific gravity of less than 1.0 will float on water, while liquids with a specific gravity greater than 1.0 will sink in water, Figure 7-3. Gasoline has a specific gravity of 0.739, and will therefore float on water.

Gas

Gas is the physical state of a substance that has no shape or volume of its own and will expand or compress to take the shape of the container or enclosure it occupies. Gaseous fuels include propane, methane, carbon monoxide, and hydrogen.

For a gas to ignite it must be within its flammable range. That is, the proportion of gas in the air must be between its upper and lower flammable limits, Figure 7-4. A concentration of gas that is too rich to burn is said to be above its upper explosive limit, or UEL. UEL is the maximum concentration of gas in air above which it is not possible to ignite the vapors. Lower explosive limit, or LEL, is the minimum concentration of gas in air below which it is not possible to ignite the vapors. A gas that is below its LEL is too lean to burn.

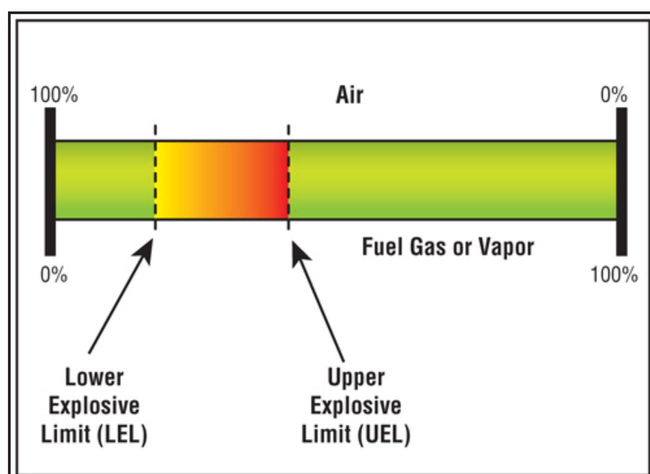

Figure 7-4 Flammability Range for a Gas

When released into the atmosphere a gas will either rise or sink, depending on its vapor density. Air is given a vapor density value of 1.0. A gas with a vapor density of less than 1.0, such as natural gas, is lighter than air and will rise when released into the atmosphere. A gas, such as butane, has a vapor

Commonly Encountered Fuel Properties

Solid	***Ignition Temperature***
Aluminum	1200° F
Steel	2500° to 2800° F
Magnesium	1200° F
Wood	450° to 800° F
Plastics	Wide Range (depending on type)

Liquid	***Flash Point***	***Specific Gravity***
Diesel Fuel	125° to 200° F	Less Than 1
Gasoline	-45 F	Less Than 1
Kerosene	100° to 165° F	Less Than 1
Linseed Oil	430° F	Less Than 1
Olive Oil	450° F	Less Than 1

Gas	***Flammable Range LEL to UEL***	***Vapor Density vs. Air***
Carbon Monoxide	12% - 75%	Lighter than Air
Hydrogen	4% - 75%	Lighter than Air
Hydrogen Sulfide	4% - 43%	Heavier than Air
Methane (Natural Gas)	5% - 15%	Lighter than Air
Propane	2.1% - 10.1%	Heavier than Air

density of greater than 1.0, which means it is heavier than air and will sink when released into the atmosphere.

Other gases include those produced by a solid (pyrolysis) or a liquid (flash point) when exposed to heat.

Oxygen

Most fires require an oxidizing agent to support the combustion process. Oxygen is a naturally occurring element in air. Air is a mixture of approximately 21% oxygen, 78% nitrogen, and 1% other elements. Oxygen is the most commonly occurring oxidizer, but others include, ammonium nitrate, fluorine, and chlorine.

Heat

The heat component of the fire tetrahedron represents heat energy above the minimum level necessary to release fuel vapors and cause ignition. The amount of heat produced by a fire or any heat source is measured in calories, or more commonly in British Thermal Units or (BTU's). The rate at which heat energy is released is known as the heat release rate (HRR). Temperature is the measure of the amount of molecular activity when compared with a reference or standard. Temperature is measured in degrees of Celsius or Fahrenheit. The temperature of a candle flame is approximately 1800 degrees F. If you had a large number of candles burning at the same time, say on a birthday cake, their respective flame temperatures would be the same (1800° F). However, the cake that has 40 candles would generate more heat energy than the same size cake with 10 candles. This is the difference between heat energy and temperature.

Figure 7-5 Chemical Heat from Oily Rag

Heat Types

For fire to occur, the fuel must be heated sufficiently to release ions into the air. Firefighters will usually find that the ignition source of a fire is the result of one of the following types of heat: chemical, electrical, mechanical or nuclear.

Chemical

For chemical ignition to occur, the oxidation must be rapid enough to reach the fuel's ignition temperature. Linseed oil soaked rags in an insulated container can heat spontaneously and ignite, illustrating a form of chemical ignition, Figure 7-5. Another example of chemical heat is microbial thermogenesis, or the decomposition of organic matter in a mulch pile. The mixing of resins and their catalysts will also cause a chemical reaction that releases heat.

Electrical

Electricity can generate heat in several ways. When electric current flows through a conductor, heat is produced, Figure 7-6. When the current exceeds its design limits it can overheat and become an ignition source. Electrical arcing caused by a short circuit or loose connection can also produce heat. Static

Figure 7-6 Electrical Heat

electricity can cause a spark, which can be a source of ignition. Lightning is another example of electrical ignition.

Mechanical

Mechanical heat energy is generated by friction or compression, Figure 7-7. When two surfaces are rubbed together, heat is caused by friction. The common match is ignited by rubbing it against a coarse, chemically treated striker, and is an example of mechanical ignition. Heat of compression is generated when a gas is compressed. Diesel engines employ very high compression ratios that produce sufficient heat to ignite the fuel/air mixture in the cylinders without using a spark plug.

Figure 7-7 Mechanical Heat

Nuclear

There are two forms of nuclear energy: fusion and fission. Fusion is the combining of atomic nuclei. Heat from the sun is an example of fusion. An atomic bomb is an example of fission, which is the splitting of an atom's nucleus. Both processes produce tremendous amounts of heat and can be sources of ignition.

Heat Transfer

One of heat's properties is its ability to transfer its energy from one material to another. When heated, the molecules of a substance increase their vibrations, causing them to contact cooler molecules and transfer energy to them. The cooler molecules absorb some of the energy, reducing the amount of energy in the warmer molecules. This process is known as heat transfer, the transport of heat energy from one point to another caused a temperature difference between those points.

The transfer of heat is a major factor in fires and has an effect on ignition, growth, spread, and decay. Heat transfer can occur through several different methods, conduction, convection, radiation, and direct flame impingement.

Conduction

Conduction is the transfer of heat within a solid and occurs when one portion of the object is heated, Figure 7-8. A fuel's ability to conduct heat is based on multiple variables. Generally, the denser a solid is, the better it is at conducting heat. Cooking utensils, such as a pot or pan, metal pipes and conduit, and even wood are examples of solids that can conduct heat. Conduction is a mechanism of fire spread. Heat conducted through a wall or along a pipe or beam can cause ignition of combustibles in contact with the heated object.

Figure 7-8 Conductive Heat

Convection

Convection is the transfer of heat energy by the movement of heated liquids or gases from the source of heat to a cooler part of the environment, Figure 7-9. The heated gases are buoyant and rise much like hot air will cause a balloon to rise. In a fire scenario, this type of heat transfer typically travels upward and outward. In the early stage of a fire, convection plays a major role in heating surfaces exposed to smoke and gases heated by the fire.

Radiation

Radiation is the transfer of heat energy from a hot surface to a cooler surface by electromagnetic waves without the need of an intervening medium, Figure 7-10. For example, the heat energy of the sun is radiated to earth through the vacuum of space. Radiant energy can be transferred only by line of sight and will be blocked by intervening materials. Radiation is the method of heat transfer that is responsible for fire spread and flashover in the advanced stages of a fire.

Direct Flame Impingement

Heat transfer from direct flame contact is a combination of both convective and radiated mechanisms.

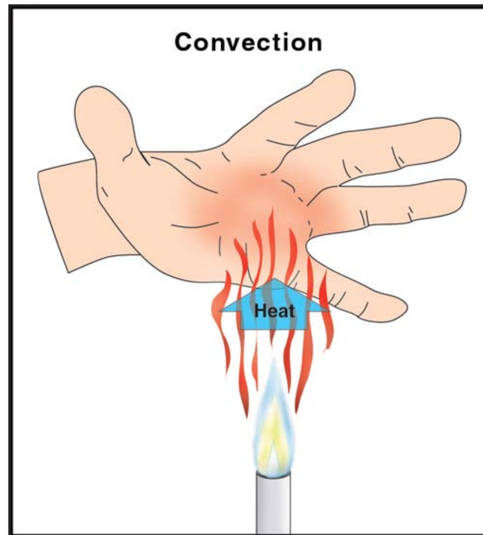

Figure 7-9 Convective Heat

Uninhibited Chemical Chain Reaction

Combustion is a complex set of chemical chain reactions that result in the rapid oxidation of a fuel, producing heat, light, and chemical by-products. Slow oxidation, such as rusting or the yellowing of a newspaper, produces heat so slowly that combustion does not occur. Self-sustained combustion occurs when sufficient excess heat from the exothermic reaction radiates back to the fuel to produce vapors and cause ignition in the absence of the original ignition source. If this process is interrupted, for example, by the introduction of dry chemical extinguishing agents, the fuel will become isolated from the oxidizer and burning will cease

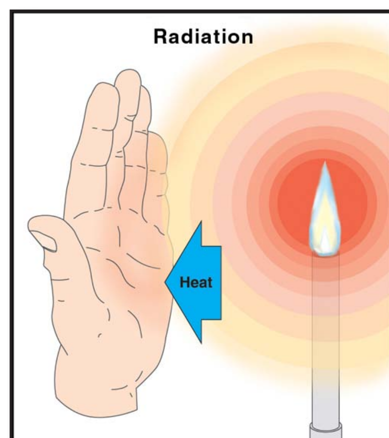

Figure 7-10 Radiant Heat

Phases of Fire

There are several distinct phases of fire; ignition, incipient, free burning, and smoldering. Each phase has its own unique characteristics and dangers. Firefighters should be able to recognize each phase and know the associated dangers. It is important to note that the phases of fire discussed below are specific to a fire in a compartment, such as a structure or vehicle. Vegetation fires, though sharing similar characteristics, develop and spread based on different factors that are discussed in the wildland firefighting section.

Figure 7-11 Ignition

Ignition

Forms and mechanisms of ignition vary with the type of fuel (solid, liquid, gas), chemical properties of the material, and the form and intensity of heating. Forms of ignition include smoldering vs. flaming ignition, and piloted vs. auto-ignition. An unattended cigarette on a sofa and a lighter igniting wood kindle are examples of smoldering and flaming ignition, respectively Figure 7-11. Pilot sources include small flames, sparks, and hot objects. For ignition to occur, there needs to be a fuel item, a competent ignition source, and an event that puts them together. The ignition source needs to have sufficient temperature, sufficient heat energy and be capable of transferring that energy to the fuel long enough to raise the fuel to its ignition temperature.

Incipient Phase

This is the beginning or growth stage of the fire after ignition. The flames are localized in the first fuel ignited and a free burning open flame is typical, Figure 7-12. The room will have a normal oxygen content of about 21%. There is a plume of hot gases rising from the flame. The contents of the plume may vary, but include soot, water vapor, carbon monoxide, carbon dioxide, and other toxic gases. Convection and buoyant flows carry these products of combustion to the upper part of the room. Though flame temperatures vary from 1500-1800° F, the overall room temperature is relatively unchanged.

Figure 7-12 Incipient Phase

Free Burning Phase

In this phase, the fire is characterized as "fuel controlled." The fire grows in intensity as more fuel is being involved. Convection and radiation spread the flames upward and outward from the initial fuel package until nearby fuels reach their ignition temperatures and begin to burn. The fire plume strikes the ceiling and the flow is diverted to flow under the ceiling as a ceiling jet. Ceiling jet gases flow in all directions, until the gases strike the walls of the compartment. As the ceiling jet flow reaches the walls and can no longer spread horizontally, the gases turn downward and begin the creation of a layer of hot gases below the ceiling. The terms "flame over" and "rollover" are often used to describe the condition where flames spread across the ceiling layer only and do not involve the surfaces of other fuels (furniture, flooring, etc.)

Figure 7-13 Flashover

As the fire continues to grow, the ceiling layer gas temperature and the intensity of the radiation on the exposed combustible contents in the room increase. Oxygen content during this phase typically is reduced to approximately 16-18%. When the ceiling layer reaches a critical temperature of approximately 1100° F it is sufficient to bring most all fuels in the compartment such as furniture, floor coverings, and smoke to their ignition temperatures. This phenomenon is known as flashover, Figure 7-13.

Thermal Layering

Thermal layering is the stratification of air and fire gases into layers based on their temperatures. When confined to a structure, the hottest of the gases and air will accumulate near the ceiling of the compartment or room, and as the amount of by-products from fire increases, the gases, heated air, and smoke will bank down until they can find an escape route, Figure 7-14.

Thermal layering is an important concept for firefighters because it affects how to enter and function in a room or area that is on fire or where the fire has just been extinguished. Firefighters must stay low to the floor when attacking structural fires because the hottest gases rise and stay at the highest layers in the compartment. One goal of interior firefighting is to keep the building in thermal balance. In essence, thermal balance is the maintenance of natural thermal layering. Fire streams can disrupt the thermal layer and, therefore, thermal balance. Efforts should be made to minimally disrupt the thermal layer so as to keep the hot air up high and the cool air down low.

Flashover

Flashover is rapid transition between the growth and fully developed fire stages. Also called thermal radiation feedback, flashover is when all of the combustibles in a compartment reach their ignition temperatures and simultaneously ignite. Another way of describing flashover is the transition from a fire in a room, to a room on fire. This occurrence is extremely dangerous for firefighters, even when wearing full personal protective gear. The only chance for survival is recognition of potential flashover and either quick fire knockdown or rapid exit from the room. Flame over or rollover within the compartment may be a sign of an impending flashover. Another signal that flashover is about to occur is the presence of extremely hot smoke forcing the firefighter to the floor. All of the combustibles in the room will begin to smoke and a rapid increase in temperature will


Figure 7-14 Thermal Layering

be felt. If the fire cannot be knocked down and these signs are present, firefighters must get out immediately.

Media 7-1 SDFD Academy Fire Demonstration

Smoldering Phase

When combustibles are completely consumed or the available oxygen has been depleted, the fire will transition to the smoldering or "decaying" phase. When the involved room is not adequately ventilated, open flame burning becomes less prevalent and smoldering combustion dominates. The fire can now be characterized as "ventilation controlled". In a ventilation controlled fire, the hot gas layer contains high levels of unburned pyrolysis products and carbon monoxide. These products can build up to form an ignitable vapor mixture.

Backdraft

Figure 7-15 Backdraft

Late in the smoldering phase of a compartment fire, the oxygen levels can be consumed to a level below the 16% required to sustain flaming combustion. During this stage the fire will produce even greater volumes of highly flammable gases, especially carbon monoxide. In an unventilated or confined compartment, these expanding gases will create a pressure within the structure, with temperatures exceeding 1300° F (700°C). When oxygen is introduced into this pressurized fuel a backdraft or smoke explosion can occur, Figure 7-15.

A backdraft is one of the most dangerous situations a firefighter can face, and therefore recognizing the warning signs and taking the appropriate action is vital. Indicators of backdraft conditions include: fire in a confined space, heavy black smoke becoming gray/yellow, puffing smoke, and hot doors and windows with heavy smoke staining. If companies at a fire note these signs, vertical ventilation must be performed prior to opening doors and windows to make entry. Vertical ventilation will release the pressurized gases in a safe direction and allow engine companies to make entry and advance hose lines to perform fire suppression.

It is important to remember that although the fire can be separated into distinct phases, the sequences of the phases are not always the same. A discarded cigarette may cause ignition of a fire by the smoldering process. It will then have to generate enough heat to transition to initiate and sustain flaming combustion. So smoldering should not be considered only to be the final phase of a fire.

Products of Combustion

Heat

Heat as a by-product of combustion is dangerous to firefighters by causing burns, dehydration as well as heat-exhaustion. Each of these conditions can be mild to severe and ultimately life threatening. The amount of heat energy released over a certain period of time is called the heat release rate. Heat release rates are influenced by the quantity and type of burning materials. When a fire burns within a room, the walls and ceiling will absorb the released heat. When the room can no longer absorb heat, it begins reflecting the heat in a radiant form. This radiant heat feedback causes burning materials to release heat at a higher rate. The radiant heat feedback will also raise floor-level temperatures significantly. The greater the heat-release rate for a particular fire, the greater the danger to firefighters for heat-related injuries.

Light

The light associated with flaming may not seem dangerous to firefighters. In most cases, this is true: the ability of the pupils of the eyes to constrict and the reflex reaction to close one's eyes self-limit the danger of light. Even so, certain types of fuels burn with a very intense light that can cause temporary or permanent damage to eyesight. Examples include the burning of metals such as magnesium, Figure 7-16. Electrical arcing can also be harmful to eyesight.

Figure 7-16 Burning Magnesium

Smoke

When a fuel burns, it can produce both visible and invisible chemical products of combustion. These products include carbon monoxide, carbon dioxide, and water vapor. If a fire has a limited amount of air or ventilation for combustion, an increase in the amount of visible products of combustion (such as soot and smoke) and carbon monoxide will occur. Smoke is the product of incomplete combustion or decomposition heating (pyrolysis) and includes an aggregate of solids, liquids and gases suspended in the thermal plume, Figure 7-17.

Figure 7-17 Incomplete Combustion, Smoke

Smoke is created by the combination of various products of combustion dependent upon the particular fuel being consumed. These products include soot, small liquid droplets, and various fire gases. Smoke can be characterized as unburned fuel.

Some fuels, such as alcohol and propane, will burn without the production of smoke. This is referred to as complete combustion. Plastics, and other hydrocarbons, produce large amounts of black smoke. As these products migrate away from the fire and cool, they accumulate on both horizontal and vertical surfaces, creating fire patterns.

For the firefighter, smoke is perhaps the most dangerous product of combustion due to its toxicity and explosiveness. With the increased quantity and complexity of synthetic materials in society, smoke has become amazingly toxic, volatile and explosive. Being able to interpret the fire's behavior based on the signs presented by smoke is a crucial element of effective and safe firefighting.

Characteristics of Smoke

When responding to structural fires, a firefighter can apply an understanding of basic fire behavior by "reading smoke." Smoke issuing from multiple openings of a structure is often the only clue as to what a fire is doing within the building. Reading smoke can help firefighters discover clues about the location of the fire within a building as well as the severity of the fire and the potential for a hostile fire event such as flashover or back draft.

Typically, firefighters view smoke as "light" or "heavy." While this is fine for a rapid radio report, it is not descriptive enough when trying to understand what is actually happening with a fire. Smoke from a structural fire has four attributes that must be analyzed, volume, velocity, density and color. These four attributes of smoke need to be compared from each opening that issues smoke. Taken collectively, the differences in attributes can paint a story about the behavior and location of fire within the building.

Volume

Smoke volume is an indicator of the amount of fuels that are "off-gassing" within a given space. In itself, smoke volume tells very little about the fire. It can, however, establish relativity about the size of the fire event. For example, it doesn't take much of a fire event to fill a small fast-food restaurant with smoke. On the other hand, it would take a serious fire event to produce enough smoke to show even a small amount of the smoke leaving a large warehouse or store.

Velocity

The speed and flow characteristic of smoke that leaves a building is referred to as velocity. Smoke velocity is an indicator of pressure that has built up within the building. Only two things can create smoke pressure, heat and restricting the volume of smoke within a container (room or building). If firefighters can define what is pushing the smoke (heat or volume), they can achieve a better understanding of the conditions within a building.

Heat-pushed smoke will leave the building and gradually slow as the smoke rises. Volume pushed smoke will slow down immediately, and will likely sink upon contact with the outside atmosphere. The flow characteristic of smoke can also help firefighters understand interior conditions.

If the flow characteristic of the smoke leaving an opening is agitated or turbulent (a rolling or boiling motion), a flashover is likely to occur. This turbulent flow is caused by the rapid expansion of the smoke due to heat. In other words, the box cannot absorb any more heat and is unable to hold the rapid expansion. In these cases, the structure must be ventilated and cooled prior to entry. Victims in these conditions have little chance of surviving due to smoke toxicity and thermal exposure.

A smooth or calm smoke flow characteristic (laminar flow) indicates that the box is still absorbing smoke heat. Comparing the velocity of smoke leaving various openings can help a firefighter locate the fire within the building.

Figure 7-18 Light, Wispy, Laminar Flow Smoke. Too Lean For Combustion

Density

Incomplete burning causes smoke to thicken (become more dense with fuel). Smoke density is indicative of the amount of fuel that is laden within the smoke. The greater the smoke density, the more likely a hostile fire event, such as flashover or rapid fire spread, can occur. In essence, the thicker the smoke, the more spectacular the flashover or fire spread. Thick, black smoke within a compartment reduces the chances of life sustainability due to the toxicity of the smoke. A few breaths of thick, black smoke will render a victim unconscious and cause death within minutes.

Figure 7-19 Thick, Turbulent, Dark Smoke. Too Rich For Combustion, Dangerous Condition.

Color

For single-fuel fires, such as dried grass, the smoke color may indicate the type of material burning. In typical residential and commercial structure fires, it is rare that a single fuel source is emitting smoke. Smoke color can, however, tell the firefighter which stage of burning is taking place or where the fire is within a building.

Virtually all solid materials will emit a white smoke when first heated. This white smoke is mostly moisture being released from the fuel. As a material dries out and breaks down, the color of the smoke will change. Natural materials like unfinished wood will change to tan or brown, whereas plastics and painted surfaces will turn to gray. Gray smoke is a result of moisture, carbon, and hydrocarbons (black) mixing. All materials will eventually off-gas a black smoke. As smoke leaves a fuel

Figure 7-20 Combustion

Media 7-2 “The Art of Reading Smoke”

that is ignited, it heats up the materials and the moisture from those objects can cause black smoke to turn gray. As smoke travels, the heavier carbon content from the smoke will deposit along surfaces and objects and eventually lighten the smoke color the further away from the fire that you travel.

Reading the Smoke

By combining these smoke attributes, some basic observations about the fire can be made before firefighters even enter a structure. Smoke velocity and color differences from opening to opening help firefighters find the location of the fire. Faster/darker smoke is closer to the fire seat, while slower/lighter smoke is farther away. If smoke from multiple openings is a constant color and velocity, firefighters should start thinking that the fire is deep-seated within the building. In these cases, the smoke has traveled some distance or has been pressure-forced through closed doors or seams prior to leaving the building.

Other factors influence smoke and may cause attributes to change. Wind, poor thermal balance, fire streams, ventilation openings, and sprinkler systems change the appearance of smoke. With study and practice, firefighters can refine their ability to read smoke and ultimately help protect their own safety and predict what fires will do next within a building.

Classifications of Fire

It is important for firefighters to understand the different classifications of fire and their characteristics. The class of fire burning will often determine which extinguishing agent or method is used to extinguish the fire. Detailed information on extinguishment methods on the different classifications of fire can be found in Chapter 10 of this manual. Fires are classified into the following general categories.

Class A - Ordinary Combustibles

Class A fires involve ordinary combustibles. These materials are wood, paper, cloth and most plastics. Fires in homes, workshops, businesses, places of assembly and also wildfires in the urban-interface environment are typically considered Class A. The majority of fires encountered by firefighters fall into this category.

Class B – Flammable Liquid & Gas Fires

Class B fires involve flammable and combustible liquids and gases such as gasoline, alcohol, paint or pressurized flammable gases. Liquid fuels must vaporize or convert to a gas to burn. Vaporization is the process in which liquids are converted to a gas or vapor. The rate of vaporization is dependent on many factors but heat will always accelerate this rate. If the vapors are above their flash point, and within their flammable limits, they will ignite with the introduction of a spark or flame. If the vapors are above their ignition temperature and in the right mix with air, they will self ignite. The growth of a liquid fire is dependent on the container holding the liquid. If burning liquid leaves the container, it will flow and spread the fire to other materials, which is referred to as a running fuel fire.

Class C Energized Electrical Fires

A class C fire is one where electrical energy is creating heat. Electrical heat that causes arcing can create temperatures in excess of 2000 degrees Fahrenheit and actually cause metals to melt or fuse. The same heat can obviously heat and ignite nearby class A or B materials. The control of a class C fire starts with a control of the electricity. Once the electrical source or power has been removed, then firefighting efforts can be made towards the remaining class A or B materials. The use of water can present extreme shock hazards while the fire is still electrically energized.

Class D Combustible Metal Fires

Class D fires involve combustible and pyrophoric metals such as magnesium, titanium, sodium and potassium and are usually found in industrial or storage facilities. Pyrophoric refers to materials that can ignite spontaneously in dry or moist air.

Combustible metals differ somewhat in their reactions under fire. In some cases, the presence of water will cause a violent reaction, releasing heat and brilliant light. In other cases, the presence of air will cause the reaction. Some metals will burn so hot that the water molecule will actually be broken down into its component hydrogen and oxygen atoms. The hydrogen will then burn away in the presence of oxygen creating a brilliant and hot fire. Each metal's characteristics must be evaluated. Fortunately, these metals are not found in great abundance in normal occupancies. They are usually found in industrial processes and their presence should be communicated in advance to responding firefighters.

Other metals are also subject to burning but only when the material is in fine shaving form or metal dust. For example, steel will not ignite easily, but a piece of steel wool will ignite rapidly when flame is applied. A particularly hazardous situation is found when dealing with airborne concentrations of metal dust. Some of the most powerful bombs in military arsenals use metallic dust. If these situations are encountered, great care should be exercised to ensure the safety of firefighters and the public.

Common Combustible Metals

Titanium – Commonly used in aerospace industry and electronics; mixed with other metals to form an alloy for use in automobiles, cell phones, sports equipment etc.

Lithium – Commonly used in electronics and batteries

Magnesium – Commonly used in mobile phones, laptop computers, cameras, and other electronic components. Older model Volkswagen vehicles may have engine blocks made out of magnesium.

Zinc – Commonly used in the process of galvanization, which is the coating of iron or steel to protect against corrosion.

Sodium – Used mainly as an alloy with other metals to improve their strength and structure

Potassium – Mainly used to produce fertilizer. It will create hydrogen gas and react violently when it comes in contact with water.

Class K Fires

The most recent class of fire, it was added in 1998 to describe fires in combustible cooking fuels, such as animal and vegetable oils and grease. Class K fires have similar properties and fire behavior to class B fires, however, utilize different extinguishing methods.

Summary

Firefighter survival and fire attack effectiveness are dependent upon firefighters and fire officers understanding fire dynamics. Fire is combustion, which is best defined as a chemical reaction that includes the self-sustaining rapid oxidation of a fuel accompanied by the release of heat and light. Four ingredients need to come together to have combustion: heat, fuel, oxygen, and a chemical chain reaction. These ingredients make up the fire tetrahedron. Principles of fire extinguishment are grounded in the process of removing one or more of the ingredients of the tetrahedron.

Heat sources include chemical, mechanical, electrical, and nuclear. Fuels are found in solid, liquid, and gaseous states, although it is the gaseous molecules present in each of these states that burn. Oxygen is a powerful catalyst that must be present for combustion. When some type of event brings these components together, a chemical chain reaction is started that becomes self-sustaining.

Once a fire begins, it will begin releasing a lot of heat. This heat is transferred to other fuels through conduction, convection, and radiation, causing fire to spread. The fire will grow in defined phases: ignition, incipient, free-burning, and smoldering.

The by-product of fire is smoke. Learning how to recognize and read the different characteristics and signs of smoke such as volume, velocity, density, and color, can help a firefighter understand the size and location of fire at hand.

Media & Links Index

- SDFD Burn Box Demonstration
- “The Art of Reading Smoke”

References

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