SECTION 2 - WHY THINGS BURN
UNIT 2 - FIRE HAZARDS OF MATERIALS

UNIT GOAL
To introduce the student to how fire affects common types of materials that exist in a solid, liquid, or gaseous state

UNIT OBJECTIVES
The Student by the End of the Semester Shall:
- List Three Common Solids That Burn
- Define Pyrolysis
- List Two [2] Examples of Each of the Following Types of Textiles
  - Natural Fiber
  - Synthetic Fiber
- Identify the Nfpa Standard That Regulates Flammable and Combustible Liquids
- Define the Following Terms
  - Flammable Liquid
  - Combustible Liquid
  - Specific Gravity
  - Vapor Pressure
  - Gas
- List Three [3] Ways Gases Are Classified
- Describe the Term BLEVE
- List Three [3] Physical Laws That Apply to Gases
- Identify the NFPA Standards for
  - LP-Gas
  - Natural Gas

KEY TERMS
Flame Spread	Liquified Gas
Fire Loading	LP-Gas
Pyrolysis	NFPA 30 - Flammable & Combustible Liquids Code
Natural Fiber	Boyles Law
Synthetic Fiber	Charles Law
Flammable Liquid	Gay-Lussac Law
Combustible Liquid	Compressed Gas
BLEVE	

INTRODUCTION
Given enough heat all materials will burn. As we learned in the previous unit one of the primary parts of the combustion triangle is fuel. Fuel can be found in one of three states - solid, liquid, gas. Depending on the state of the material will determine what hazards it will possess in a fire situation.

In this unit we will discuss the fire hazards of solids, liquids and gases and some of the physical laws that impact them.

COMBUSTIBLE SOLIDS

As mentioned in the previous unit all materials must be in a vapor state before they can burn. Any solid object must be heated to a point where it gives off ignitable vapors. A solid object is considered any object that has a definite shape and volume.

There are three common forms of solids that are combustible.
Wood and its byproducts [paper, cardboard, etc.]
- Plastics and synthetic materials
- Textiles

Wood

Wood comes from living organism, i.e., plants. It is a cellulose material with a complex chemical makeup. In its natural state it contains a high amount of moisture which can retard its burning. Wood is composed primarily of Carbon, Hydrogen, and Oxygen. Wood is a common material in the building industry, publication industry, and the packaging industry. Wood is responsible for any of the paper products we use and much of the packaging material we use. While it may be in a different form it is still wood based and has the same inherent burning characteristics.

How wood burns is dependent on what form it is in. In a solid [log, beam] it will be harder to ignite. When made into shavings it will burn more easily. Wood by products have ignition temperature between 350^0 F. to 600^0 F. The rapidity of its burning is dependent upon the following
- moisture content
- surface area of wood object
- the intensity of the heat source and the time applied.

Low density soft woods [pine, spruce] will ignite more readily than hard density woods [oak, maple]. Wood building materials will be affected by the type of wood they are. They will also be affected by the size or dimension they are. Small dimension lumber, such as, used in truss construction will burn more quickly than larger dimension lumber used as support beams.

Pyrolysis

Definition - The decomposition of a material brought about by heat. The process of a fuel decomposing into a vapor state so as to burn.

As heat is applied to wood or wood by-products vapors are emitted by the material. This process can start at low temperatures and continue until combustion occurs. It can also occur over a period of time and cause extensive charring and decomposition of the material. If this continues without ignition occurring the only material that will be left is carbon, since all other materials that compose wood have vaporized.

There are four stages of decomposition of wood
- 392^0F - Water Vapor, CO_2, Formic Acid Formed - All Noncombustible Gases
- 392^0F - 536^0F - less Water Vapor, More CO

- 536^0F - 932^0F - Flammable Vapors and Particulate
- Over 932^0F - Residue principally charcoal with notable catalytic action

Flame Spread
When dealing with combustible solids a major concern is how fast flame will spread across the surface of the material. Through testing processes a rating can be applied to various materials to determine the extent of the hazard. The higher the rating number the more hazardous the material. Tests such as this are a direct result of fires such as, the Iroquois Theater fire and the Coconut Grove fire.

Fuel or Fire Loading
It is also possible to determine the fire hazard of a structure by estimating the amount of fuel in the building that will be involved in the fire. This is called *fire loading*. This is accomplished by determining the *BTU* output of the material. For wood it is about 8,000. By determining the total weight of the wood products that make up the structure and multiplying that by 8,000 BTUs you can roughly determine what the fuel load in the building is. This can help in determining how much water would be necessary to extinguish the fire.

Storage
Wood or its by-products when stored in bulk must have adequate protection if a fire occurs.
- Cardboard and paper products when stored in bulk inside a structure should be protected by an automatic sprinkler system
- Wood when in bulk is usually stored outdoors (lumber yard)
- Usually stored in parallel forms that do not exceed 15 feet
- Most fire codes limit amount that can be stored inside a building (pallets)
- Wood chip storage requires special considerations

PLASTICS
Since the 1960s our society has relied more and more on plastics in the development of products. There is very little in your home or workplace that doesn't have plastic components in it or is made completely of plastic.

From a fire safety standpoint plastics offer a challenge. There are thousands of types of plastics manufactured, each with there own particular hazards. Some of these hazards are when plastic is in tis raw state, others are when it is a finished product.

Plastics are not a natural product, they are man-made. They are produced from materials that come from the oil fields. Their chemical makeup can be very simple or complex.. They come in various shapes and sizes, from sheets, to foams, to molded forms, to fibers, to pellets and powders.

Fire Behavior of Plastics
How plastics burns depends on several things
- chemical composition
- additives used
- shape and size

Some plastics will melt and behave as a flammable liquid. Others will melt, and others will burn and char, similar to wood. The *ignition temperature* of the plastics will vary greatly also, but will tend to ignite before 1,000 degrees F.

One of the major concerns with fires involving plastics is the creation of many toxic gases which are carried in some that it emits. The color of the smoke in plastic fires is usually black due to the high amount of carbon in its chemical makeup. Some of the common gases given off by plastics are:

- Carbon Monoxide
- Acrolein **{ known carcinogens }**
- Benzene **{ known carcinogens }**
- Phosgene
- Hydrogen Cyanide

Storage

How plastic is stored is usually based on the finished product, i.e., bags, solid shapes, etc. Because of the high heat output and rapid spread, most areas where plastics are stored are protected by automatic sprinklers

TEXTILES

Some of the major causes of many fire injuries are the things that we wear, sleep on, and relax in. These are items that make up what is called textiles. These include clothing, bedding, and upholstery. How they burn are impacted by their chemical composition, types of weave, and the finishing treatment used. Many of the fire injuries related to young children and the elderly are directly related to fires involving textiles.

Types of Textiles

There are two common types of textiles - natural fibers and synthetic fibers. Natural fibers come either from plants or animals. Synthetic fibers are a direct result of the petro-chemical industry and are entirely man-made.

Natural Fibers

Plants

Common plant fibers are cotton and hemp. Cotton is a very popular material for children's clothing due to it softness to the touch. While common and popular cotton material is also highly combustible when subjected to a heat source. They will burn quickly but will not melt. Hemp is a material that is used in upholstery and is also very combustible.

Animals

The most common material is wool which comes from sheep. Other materials used are types of fur that come from a variety of animals. Unlike cotton and hemp these tend to smolder instead of rapidly combust. They can give off some rater toxic vapors such as Hydrogen Cyanide.

Synthetic Fibers

As far as clothing goes these are the most popular types of materials. Many upholstered fabrics also come from synthetic fibers. The more common types are rayon, cellulose acetate, nylon, polyester, and spandex. Unlike natural fibers these materials will melt and flow just like plastics.

Flame Retardant Textiles

Materials used in children's clothing are commonly treated with fire retardant chemicals to limit the spread of fire as are bedding materials. This is due to the high amount of injuries among children and the high amount of fires involving bedding materials There primary purpose to prevent rapid flame propagation over the surface of the material.

Firefighter protective clothing is also made fire retardant material. This allows firefighters to exist in environments of elevated temperatures for longer periods of time. Some of the material used is

- ♦ Nomex ®
- ♦ Kevlar
- ♦ PBI

COMBUSTIBLE & FLAMMABLE LIQUIDS

A liquid is defined as *"any fluid having a vapor pressure of 40 psia or less.* Liquids have volume, but no shape of own. From a fire protection standpoint there are two categories of liquids that are of concern, these are f*lammable* and *combustible liquids*. Additional information on the classification of liquids can be found in **NFPA Standard 321,** *Standard on the Basic Classification of Flammable and Combustible Liquids* and **NFPA Standard 30,** *Flammable and Combustible Liquids Code* which is the main reference for storage and handling of flammable and combustible liquids

Flammable Liquids

Any liquid having a flash point below 100^0f and having a vapor pressure not exceeding 40 psia. They are further categorized as:

- ♦ class Ia liquids - flash point below 73^0F and a boiling point below 100^0F
- ♦ class Ib liquids - flash point below 73^0F and a boiling point at or above 100^0F
- ♦ class Ic - flash point at or above 73^0F and below 100^0F

Examples of Flammable Liquids

- ♦ Acetone - Class Ib
- ♦ Gasoline - Class Ia

Combustible Liquids

Any liquid having a flash point at or above 100^0F

- ♦ Class II liquids - flash point at or above 100^0F and below 140^0F
- ♦ Class IIIA liquids - flash point at or above 140^0F and below 200^0F
- ♦ Class IIIB - flash point above 200^0F

Examples of Combustible Liquids

- ♦ #2 Fuel Oil - Class II
- ♦ Peanut Oil - Class IIIb

Characteristics of Flammable & Combustible Liquids

- ♦ **Vapor Pressure** - a measure of the tendency of a substance to evaporate and the vapor to air mixture above the liquid in a container.
- ♦ **Flash Point** - the minimum temperature at which a liquid fuel gives off sufficient vapors to form an ignitable mixture with air near the surface. At this temperature, the ignited vapors will flash

but will not continue to burn.

- **Boiling Point** - the temperature of a substance when vapor pressure exceeds atmospheric pressure (14.7 psi). At this temperature, the rate of evaporation exceeds the rate of condensation. At this point more liquid is turning into gas than gas is turning into liquid.
- **Specific Gravity** - the density of a liquid in relation to water. Water has a value of 1.
- **Evaporation Rate** - rate at which the liquid is converted into a vapor at a given temperature and pressure.
- **Viscosity** - a liquid measured in relation to the time required for the liquid to flow into a container or through an opening.
- **Latent Heat of Vaporization** - the amount of heat required to convert one gram of liquid into vapor at the boiling point under one atmosphere pressure.
- **Ignition Temperature** - the minimum temperature to which a fuel in air must be heated to start self-sustained combustion with out a separate ignition source.

Storage and Handling of Flammable and Combustible Liquids

- proper storage is required to limit the possibility of fire
- ventilation is necessary to dissipate flammable vapors
- limit exposure to possible ignition sources
- must be bonded or grounded when being transferred because flammable liquids create static charge when flowing
- petroleum based liquids have heavier than air vapors and tend to collect in low spots on the ground
  - gasoline, fuel oil, kerosene are petroleum based fuels

GASES

A gas is matter that is made up of molecules that are in constant motion. The higher the temperature the more motion. Gases have no shape or volume. It will occupy and take the shape of the container it occupies. A gas is defined as "*a substance is a gas when it has an absolute pressure exceeding 40 psia.* Gases are usually classified by its chemical or physical properties or by its usage.

Chemical Properties

- Flammable Gas
  - a gas that will burn in air with 21% oxygen and is within the proper flammable range
  - **example - Hydrogen**
- Nonflammable Gas
  - a gas that will not burn in air or any concentration of oxygen
  - also known as "inert gases"
  - **examples - Nitrogen, CO2, Argon, Helium**
- Toxic Gases
  - any gases that are a danger to life if inhaled
  - **examples - Chlorine, Ammonia, Carbon Monoxide, Sulfur Dioxide (these are common gases created during combustion)**
- Reactive Gases
  - gases that will react with other materials by a reaction other than burning
  - **examples - Acetylene, Vinyl Chloride**

Physical Properties

- Non-liquefied Compressed Gas
    - at normal temperatures inside a container exists only as a gas
    - common types are - Hydrogen, Nitrogen, Argon, Helium, Oxygen, Ethylene
    - usually containers do not contain a lot of gas
    - some gases are nonflammable - CO2, Argon, Nitrogen
    - some are flammable - Hydrogen, Ethylene
    - some will support combustion - Oxygen
- Liquefied Gases
    - These can be liquefied at 70^0F by increasing temperature
    - common types are Propane, Butane, Ammonia and Chlorine
    - when stored in container will exist in both a gaseous and liquid state (usually 80% liquid & 20% gas (vapor))
    - Acetylene is a liquefied gas that is very reactive and must be stored in special containers
- Cryogenic Liquids
    - liquids made from gases that are liquefied by cooling to very low temperatures
    - National Bureau of Standards defines cryogenic liquid "*as a liquid having a boiling point below- 238^0F"*
    - common types are Oxygen, Nitrogen, Hydrogen, Argon, Helium, Liquefied Natural Gas (LNG)
    - must be maintained in containers as low temperature liquids at low pressure
    - must be stored below their boiling points to prevent pressure build up

Usage Classifications

- Fuel Gases
    - flammable gases used for burning with air or Oxygen to produce heat, power or light
    - types are Propane and Butane
- Industrial Gases
    - used in industrial processes for welding, heat treating, chemical processing, refrigeration
    - types include Acetylene, Freon, Chlorine
- Medical Gases
    - a specialized use that can be for anesthesia and respiratory therapy
    - **types are Oxygen and Nitrous Oxide**
    - are either labeled as a drug or medical device and controlled by the FDA [Food & Drug Administration]

GAS LAWS

Volume (V), pressure (P) and temperature (T) are very important physical properties of a gas. They not only determine the behavior of a gas, but they are also very interrelated. Any change in one of these items will always change one or both of the other properties. This is explained in the following gas laws.

- **V and P change**: If held at constant temperature, the volume of a given mass of gas is inversely related to the pressure it exerts. This is called *Boyle's Law*, named after Robert Boyle, an English chemist (1627-1691). This law means an increase in the volume of a gas will cause a decrease in gas pressure. Likewise, if you increased the gas pressure, the volume of the gas would decrease. Assuming in both cases, the mass and temperature of the gas do not change. Now let's consider an example. First, we will place a fixed amount of gas into the air chamber of a bicycle air pump and plug the gas outlet valve. Now if we push the piston towards the gas, we will increase the gas pressure inside the cylinder. What will happen to the volume of the gas? This will compress the gas, decreasing its volume.. As expected, the V and P change was inversely related.

- **V and T change:** If held at constant pressure, the volume of a given mass of gas is directly related to the absolute temperature of the gas. This is called *Charles' Law*, after Jacques Charles, a French physicist who developed it in 1787. This law means a fixed mass of gas held at a constant pressure will increase in volume if the gas is heated (increases in temperature). Likewise, it will shrink in volume if the gas is cooled. This is exactly what happens to the volume of a gas filled balloon when its subjected to a temperature change. To see for yourself, take an air filled balloon into a hot dry sauna or place it in a refrigerator for one hour.

- **P and T change:** If held at a constant volume, the pressure of a given mass of gas is directly related to the absolute temperature of the gas. This is *Gay Lussac's Law*. It is a common observation that a rise in temperature increases the pressure of a gas, having a fixed volume and mass. Likewise, if you cool this gas, its pressure will drop. It is this relationship of (P) and (T) that is often responsible for the blow out of an automobile tire. As the car moves down the road, the air within the tire starts to heat up. This, in turn, increases the pressure of the gas, without any volume change, and eventually ruptures the tire.

GAS FIRES

Gas fires are normally classified as a *BLEVE* (Boiling Liquid - Expanding Vapor Explosion) - This is when a fires occurs near a container filled with gas. Iit causes an increase in pressure in the container, in order to prevent a rupture due to over pressurization the relief valve on the container will activate when its relief pressure is reached. If the pressure exceeds the relief device the container can fail and become a flying missile. Or a *Combustion Explosion*. - Any gas that is heated will have an increase in volume and pressure, if this continues the container that it is in will fail. This container can be a cylinder, room or structure. A common example of this is a *Backdraft* or smoke explosion

BLEVE

These have happended several times to propane containers during the 1970s and 1980S

- Crescent City, Iowa
- Oneanta, New York
- Kingman, Arizona
- Buffalo, New York
- Waverly, Tennessee

The acronym BLEVE stand for Boiling Liquid Expanding Vapor Explosion. The explosion occurs when a container breaks into 2 or more pieces when the liquid inside the container is at a temperature that is higher than its boiling point at normal atmospheric pressure. While it is believed that this can occur only with flammable materials, such as, LP-gas this is not true. Any contained liquid when raised beyond its boiling point can BLEVE if there is container failure. One thing to remember is the difference between a BLEVE an a rupture. A rupture is when a hole is caused in the container, while a BLEVE is when there is complete container failure.

Container failure can be cause by several things. By mechanical damage, like an impact, by chemical damage, corrosion, or by thermal damage, like exposure to fire.

Inside a pressurized liquid container is a vapor space above the liquid. As the flame contact the lower sides of the container, the temperature of the liquid rises. The boiling liquid vaporizes, increasing the vapor pressure. If the liquid level is above the point of flame impingement, the liquid absorbs the heat and prevents fatigue of the container. As the gas pressure increases, a relief valve on the container will bleed off excess pressure. If the liquid is flammable, the escaping gas can easily be ignited by the exposing flames. As the liquid boils off the liquid level drops. When the flame impinges on the vapor space of the container, the vapors in the container are unable to absorb the heat that leads to a rise in the metal container's temperature. Metal fatigue will cause a rupture, perhaps making the incident a BLEVE. Containers can fail without the relief valve opening.

BLEVE's involving a nonflammable liquid will cause a large explosion and shock wave and a large cloud of vaporized liquid. In a BLEVE involving a flammable liquid or gas, the vaporized cloud may ignite and cause a destructive fireball that can spread over a wide area.
Container parts have been known to travel more than ½ mile.

The time between the initiation of flame contact and a BLEVE varies because it depends upon such widely varying factors as the size and nature of the fire along with the type container. A study of LP-gas storage container ranging in size from 1,000 to 30,000 gallons showed a time range from 8 to 30 minutes with just over 50% occurring in 15 minutes or less.

Propane or LP-Gas

The liquefied petroleum gas industry provides more than 18 million residential, farm, commercial, industrial, and recreational vehicle customers with modern gas service that is dependable and safe. A rough calculation of the total market in the United States indicates that approximately 60 million people depend on lp-gas for more and more uses. During 1976, all classes of consumers in the U. S. used more than 16 billion gallons of lp-gas, and an increase of 33% in just 10 years.

The dimensions of the LP-gas industry are as impressive as the industry's rapid growth in sales volume and numbers of customers served since its founding 76 years ago. Capital investment in the industry in the excess of $7.5 billion includes 225,000 miles of pipelines in which LP-gas is transported, 25,000 transport and delivery trucks, 22,000 railroad tank cars, 250 primary storage facilities with capacity of 7 billion gallons, a fleet of 150 barges and tankers, 8,000 bulk storage and distribution points and 25,000 retail outlets. The distribution of LP-gas to millions of consumers requires the effort of more than 86,000 people in the industry.

As one of the nation's most versatile sources of energy, LP-gas is stored and transported as a liquid under moderate pressure, the liquid occupies a mere 1/270th the space of the gas. When withdrawn from its container either in liquid or vapor form, depending on its use in appliances and equipment, the liquid is changed to a clean-burning gas similar to natural gas. The principle LP-gases are propane and butane, but propane is the predominant fuel.

Propane is a flammable compressed gas that is normally stored as a liquid in a pressurized container. Propane is a hydro-carbon fuel that is processed from the same material that gasoline and diesel fuel are - that being crude oil. When propane is release to the atmosphere from its container it will have an expansion ratio of 270 to 1. The DOT Emergency Guidebook number for propane is **1075**. The properties of propane are provided in the following table.

Propane or LP-Gas Control Measures

Fire fighters responding to a propane incident should ask the following questions when they arrive at the scene.

1. What is the size and type of the container?
2. Is there mechanical damage to the container?
3. Is there a leak? Is there a fire?
4. Is there flame impingement on the tank?
5. What is the availability of water?

The fire department must realize that their involvement is directly proportional to the capabilities and resources available. If a leak/fire does exist, sufficient materials and technical assistance should be called for. The area should be isolated first thing. The first arriving officer should survey the area and determine the extent of the danger. If there is damage to the shell, the area should be evacuated until an analysis of the problem can be done. Evacuation should be done in accordance with the DOT Emergency Guidebook.

The following procedures can be used for a leak and NO FIRE.

♦ Remove all possible ignition sources.
♦ Consider downwind ignition sources up to ½ mile away.
♦ If possible under the protection of a fog stream attempt to shut off the flow of gas.
♦ If you are unable to shut off the flow of gas then an attempt to dilute the vapor cloud that is leaking with a fog stream. Be careful to remember that propane is heavier than air and will seek low areas

The following are procedures that can be taken if there is a FIRE involved.

♦ If there is an adequate water supply available the objective will then be to get large quantities of water using fire streams on ALL sides of the container as quickly as possible. The MINIMUM fire flow that is recommended is 500 G.P.M. at each point of flame impingement. These streams should be concentrated on the upper vapor space and allow the water to run down the sides.
♦ **IF THERE IS NOT AN ADEQUATE AND CONTINUOUS SUPPLY OF WATER THEN THIS ATTACK SHOULD NOT BE ATTEMPTED. THE PROCEDURE SHOULD THEN BE TO ABANDON OPERATIONS AND WITHDRAW FROM THE AREA.**
♦ The purpose of water application is for COOLING purposes and NOT for extinguishment.
♦ NEVER extinguish the flames coming from a relief valve.

While there is no clear way to determine when a container may fail, there are some warning signals that can indicate that the situation is worsening.

- ♦ A pinging sound that occurs when metal has been softened by high heat and the pressure is stretching the metal.
- ♦ Discoloration of metal shell usually in an isolated location due to impinging flame; color turns from grey to an off-white with small thin pieces of metal flaking off. A bulge or a bubble is an other indicator of serious localized heating of the shell in the vapor space. The metal is softening and beginning to thin since there is no cooling of the shell.
- ♦ Activation of the pressure relief valve. It indicates that pressure is continuing to build up in the cylinder. Actions must be taken to reverse this trend.
- ♦ The torch from the pressure relief valve continues to increase. If the fire or torch coming from the pressure relief valve increases in intensity, the pressure in the cylinder is also increasing; on scene cooling techniques are not adequate.
- ♦ The sound from the pressure relief valve is increasing due to a greater volume of gas rushing out, indicating an increase in the internal boiling and vapor production.
- ♦ The pitch from the pressure relief valve is increasing as the gas is exiting at a greater velocity, indicating a continuing increase in pressure.
- ♦ Visible steam is coming from the tank surface. If this occurs when water is applied, the tank shell is over 212°F, and must be cooled quickly to avert a disaster.

Gas Containers

Pressure containers can be as small as a butane cigarette lighter. These are usually made of plastic. The smallest metal containers are those used in hobby crafts. These are both disposable types of containers.

Motor homes have tanks that range in size from 5 gallons to 50 gallons of propane. The largest containers are those of rail road tank cars. These contain from 4,000 to 33,000 gallons of propane liquid. Containers in fixed facilities can contain hundreds of thousand of gallons of propane.

Those containers that are metal are usually steel. The disposable types can be made of aluminum. All of these have some form a pressure relief device installed in them. These are designed to relieve an excess pressure in the container that is due to expansion of vapor from an increase in temperature. The construction of these cylinders is based on DOT (Department of Transportation) and ASME (American Society of Mechanical Engineers) standards and specifications. The wall thickness is one of the many things that are specified. The wall thickness can vary from 3/4" to over 1". This will depend on the container size and the pressure that it is required to stand.

Gas Standards

LP Gas, Oxygen, Acetylene and other gases shipped and stored in containers are controlled by standards and regulations by the NFPA AND Federal Government. Cylinders that store gas must meet **DOT (Department of Transportation)** and **ASME (American Society of Mechanical Engineers)** codes and standards. Nfpa Standards are

- ♦ NFPA 58 - PROPANE
- ♦ NFPA 54 - FUEL GAS

RECOMMENDED REFERENCES

- ■ NFPA Fire Protection Handbook, 18th Edition, 1997, NFPA
- ■ Flammable and Combustible Liquids Code Handbook, 6th ed., Benedetti, 1996, NFPA

- Industrial Fire Hazards Handbook, 1990, NFPA
- L-P Gases Handbook, 4th ed. Lemoff, 1995, NFPA