PROCESS SAFETY ENGINEERING (0905477)

13- FIRES AND COMBUSTION: LIQUID AND SOLID FUELS

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The superior man, when resting in safety, does not forget that danger may come.... When all is orderly, he does not forget that disorder may come. Confucius (551 BC – 479 BC)

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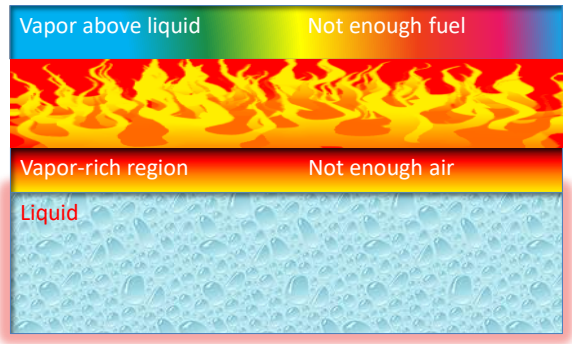
Outline

- Liquid Fuels
  - Flash Point, Autoignition Temperature and Fire Point
  - Limiting Oxygen Concentration (LOC)
  - Flash Points and Autoignition Temperatures
  - Minimum Ignition Energies (MIE)
  - Ignition Sources
  - Classification of Flammable and Combustible Liquids
  - Flammable Versus Combustible Liquids
  - Grounding and Bonding
  - Liquid Combustion
- Solid Fuels
- Pyrophoric Materials

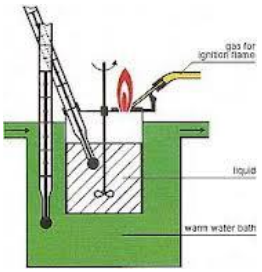
Liquid Fuels

- Liquids do not burn, but gives off flammable vapour. **It is the vapour which burns**.
- Liquids which give a lot of such vapours are called **HIGHLY FLAMMABLE LIQUIDS**.



Flash Point, Autoignition Temperature and Fire Point

- Every liquid has a vapor pressure, which is a function of that liquid's temperature.
- As the temperature increases, the vapor pressure increases. As the vapor pressure increases, the concentration of vapor of the flammable liquid in the air increases.
- Hence, temperature determines the concentration of vapor of the flammable liquid in the air. A certain concentration of vapor in the air is necessary to sustain combustion, and that concentration is different for each flammable liquid.



Flash Point, Autoignition Temperature and Fire Point

- The **flash point** of a flammable liquid is the lowest temperature at which there will be enough flammable vapor to ignite when an ignition source is applied.
- The **autoignition temperature (AIT)** or **kindling** point of a substance is the lowest temperature at which it will spontaneously ignite in a normal atmosphere without an external source of ignition, such as a flame or spark.
- Most common flammable and combustible liquids have AIT in the range of 200-500°C.
  - Some have very low AIT. For example, diethyl ether has an autoignition temperature of 160°C, and its vapors have been ignited by hot steam pipes. Silane has an AIT of 21°C.
- The **fire point** of a fuel is the temperature at which it will continue to burn for at least 5 seconds after ignition by an open flame.
- At the flash point, a lower temperature, a substance will ignite briefly, but vapor might not be produced at a rate to sustain the fire. In general the fire points can be assumed to be about 10°C higher than the flash points. However, this is no substitute for testing if the fire point is safety critical.

Limiting Oxygen Concentration (LOC)

- Oxygen concentration below which combustion is not possible, with any fuel mixture.
  - Expressed as volume % oxygen.
- Also called: Minimum Oxygen Concentration (MOC) and Max. Safe Oxygen Conc. (MSOC).

	LFL	UFL
Methane:	5.3%	15%
Propane:	2.2%	9.5%
Butane:	1.9%	8.5%
Hydrogen:	4.0%	75%

See Appendix B

	Flash Point Temp. (deg C)
Methanol:	12.2
Benzene:	-11.1
Gasoline:	-43

	AIT (deg. C)
Methane:	632
Methanol:	574
Toluene:	810

Appendix B

Great variability in reported AIT values! Use lowest value.

	LOC (Vol. % Oxygen)
Methane:	12%
Ethane:	11%
Hydrogen:	5%

Table 6-2

Flash Points and Autoignition Temperatures

Fuel	Flash point (°C)	Autoignition temperature (°C)
Ethanol (70%)	16.6	363
Gasoline (petrol)	−43	280
Diesel	>62	210
Jet fuel	>60	210
Kerosene (paraffin oil)	>38–72	220
Vegetable oil (canola)	327	
Biodiesel	>130	

Which component is the most prone to fires under normal conditions?

Minimum Ignition Energies (MIE)

- Energy required to ignite a combustible vapor, gas or dust cloud.

Fuel	MIE (μJ)
Explosives, hydrogen, unsaturated hydrocarbons and alkanes in oxygen	1-100
Alkanes in air, distillate fuels, hybrid mixtures and extremely sensitive dusts	100-10,000
Combustible dusts	10,000-1,000,000
Static spark that you can feel	~20,000

Flammability Limits of Mixtures

- Le Chatelier Rule (1891)

Le Chatelier Rule (1891)

$$LFL_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{y_i}{LFL_i}} \qquad UFL_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{y_i}{UFL_i}}$$

y_i is the mole fraction of component i on a combustible basis, and n is the number of combustible species.

Assumptions:

1) Product heat capacities constant
2) No. of moles of gas constant
3) Combustion kinetics of pure species unchanged
4) Adiabatic temperature rise the same for all species

Ignition Sources

Electrical (wiring of motors)	**23%**
Smoking	18%
Friction	10%
Overheated materials (abnormally high temperatures)	8%
Hot surfaces (heat from boilers, lamps, etc..)	7%
Burner flames(improper use of torches, etc..)	7%
Combustion sparks(sparks and embers)	5%
Spontaneous ignition (rubbish, etc..)	4%
Cutting and welding (sparks, arcs, heat, etc..)	4%
Exposure (fires jumping into new area)	3%
Incendiarism (fires maliciously set)	3%
Mechanical sparks (grinders, crushers, etc..)	2%
Molten substances(hot spills)	2%
Chemical action (processes not in control)	1
Static sparks (release of accumulated energy)	1
Lightning (where lightning rods are not used)	1
Miscellaneous	1

Prevention manual for industrial Operations (Chicago: National Safety Council, 1974).

Ignition Sources in Jordan (1996-2004)

Type	Percentage
1. Children carelessness	32.1
2. Arson	20.2
3. Smoking	14.7
4. Electrical wiring and equipment	12.5
5. Carelessness	7.9
6. Gas leak	5.5
7. Heaters	1.7
8. Friction	0.9
9. Car accident	0.8
10. Cutting and welding sparks	0.7
11. Spontaneous ignition	0.2
12. Negligence	0.2
13.Miscellaneous	2.6
	100%

Dr. Fawaz Sweis data from Department of Civil Defence.

Classification of Flammable and Combustible Liquids

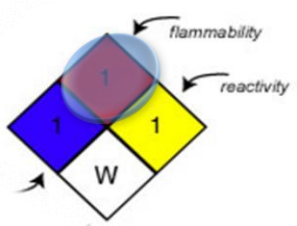
- OSHA standard 29 CFR 1910.106 – Flammable and Combustible Liquids
  - **Flammable** liquids has a flash point below 100°F (37.8°C) and a vapor pressure not exceeding 40 psi (abs) at 100°F (37.8°C).
  - **Combustible** liquid has a flash point at or above 100°F (37.8°C).
- It is important to note that such classification is used primarily to determine the appropriate code requirements for **storage, transportation, use and protection**.

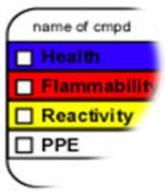
Flammable and Combustible Liquids (Class I, II and III)

Class	Classification	Flash point	Boiling point	Example
IA	Flammable	< 73°F < 22.8°C	< 100°F < 37.8°C	Acetaldehyde, ethylene oxide, ethyl ether, methyl chloride, heptane, pentane, propylene oxide, vinyl chloride
IB	Flammable	< 73°F < 22.8°C)	≥ 100°F ≥ 37.8°C	Acetone, ethanol, gasoline, isopropyl alcohol, methanol, methyl ethyl ketone, octane, toluene, hexane.
IC	Flammable	73°F ≤ T < 100°F 22.8°C ≤ T < 37.8°C	All Boiling points	Isobutyl alcohol, mineral spirits, styrene monomer, turpentine, xylene, butyl acetate
II	Combustible	100°F ≤ T < 140°F 37.8°C ≤ T < 60.0°C		Diesel fuel, fuel oil, kerosene, motor oil
IIIA	Combustible	140°F ≤ T < 200°F 60.0°C ≤ T < 93.3°C	All Boiling points	Furfural, linseed oil, mineral oil, oil based paints
IIIB	Combustible	≥ 200°F ≥ 93.3°C		Ethylene glycol, glycerine, neatsfoot oil

NFPA Diamond: Flammable is Red

Rating	Degree of flammability	Examples
0	Materials that will not burn	Water
1	Materials that must be preheated before they will ignite	Lubricating oils, cooking oils
2	Materials that must be moderately heated or exposed to relatively high ambient temperatures before they will ignite	Diesel fuel
3	Liquids and solids that can ignite under almost all temperature conditions	Gasoline, acetone
4	Materials which will rapidly vaporize at atmospheric pressure and normal temperatures, or are readily dispersed in air and which burn readily	Natural gas, propane, butane





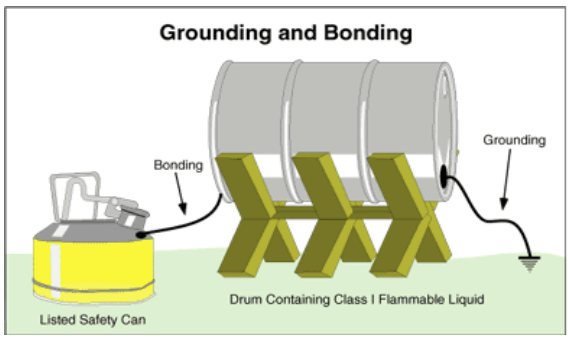
Flammable Versus Combustible Liquids

- The major distinction between flammable and combustible liquids is **ease of ignition**, not **fire severity**.
  - At normal, ambient conditions, flammable liquids produce enough vapor that even small sources of ignition may be enough to start a fire.
  - Combustible liquids require either a strong ignition source or preheating of the liquid for it to be ignited.
- It is important to note that the flash point measurements are based on standard test methods. The flash point generally increases with increasing pressure. It also depends heavily on the oxidizing medium. The data so obtained cannot be extended to practical conditions unless possible variations in the ambient conditions are taken into account.

Grounding and Bonding

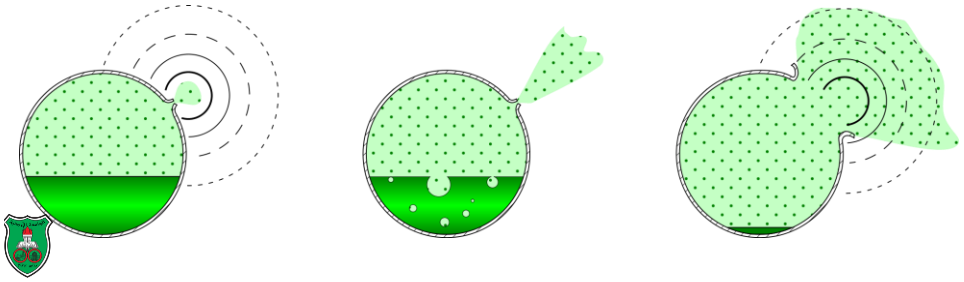
- When flammable and combustible liquids travel through a pipe or through the air, static charges are accumulated.
- Grounding and bonding is necessary during the transfer of **Class I flammable liquids** to prevent a static spark from igniting the flammable vapors.

Safety Can: A listed container with a capacity of no more than 5 gallons that has a spring-closing lid and spout cover and is designed to safely relieve internal pressure when exposed to fire.



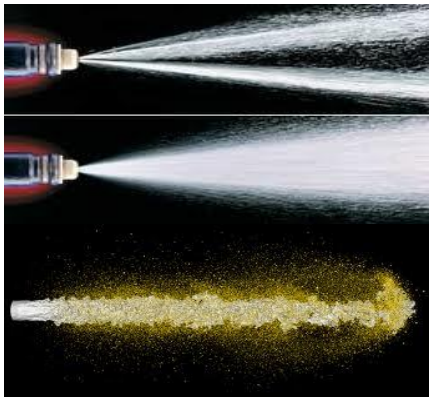
Liquid Combustion

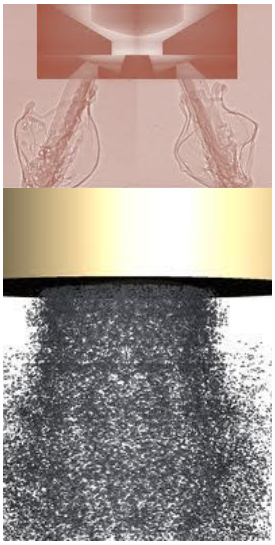
- **A liquid above its Flash Point**
  - Will give vapour which can travel some distance away.
  - This vapour can ignite.
  - These vapours are always heavier than air. So will flow down, unless there is a strong wind.
  - Can lead to BLEVE.



Liquid Sprays

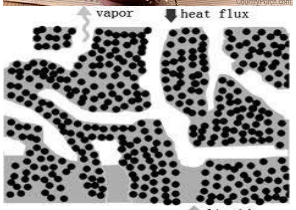
- Can burn even below their flash point because they give a higher concentration in air.

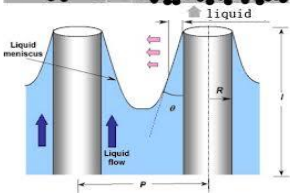


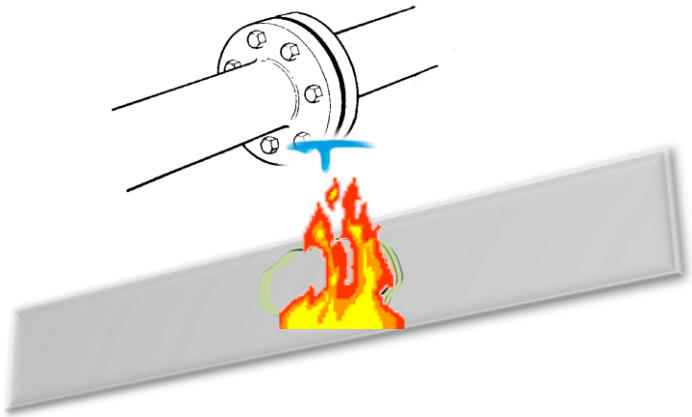


Liquid Wicks

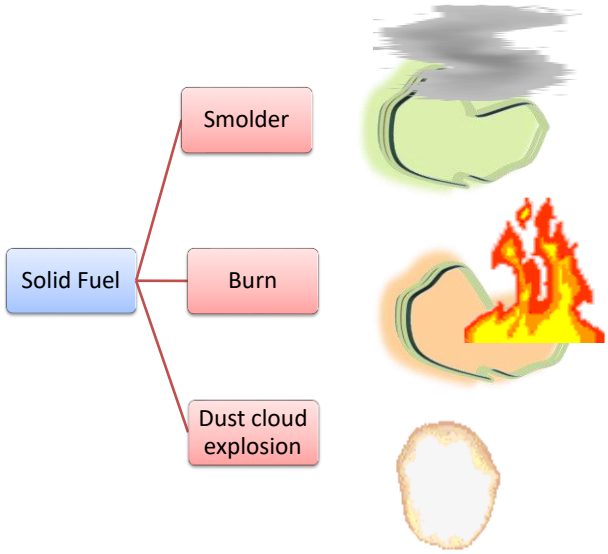
- A liquid below its Flash Point may burn if it is on a porous material e.g., wick.
  - The liquid fuels travel up the cloth, which is acting as a wick. When the liquid reaches close to the flame and passes its flash point, the liquid vaporizes and may then react with oxygen.
  - For example, oil on pipe lagging







Solid Fuels



Pyrophoric Materials

- Some metal catalysts are **PYROPHORIC.** They ignite spontaneously in air so need to be kept under nitrogen
  - Examples are iron sulfide and sodium hydride, lithium aluminium hydride and many reactive metals including uranium, when powdered or thinly sliced.
  - The creation of sparks from metals is based on the pyrophoricity of small metal particles, and pyrophoric alloys are made for this purpose.
  - Nano materials are pyrophoric (most of them. they have to be handled in vacuum.

Plutonium's pyrophoricity can cause it to look like a glowing ember under certain conditions.

شكرا لحسن ألاستماع

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