CE 400 / CE 500

Process Safety Management

Lecture 08 Fire and Explosions

Fire Triangle

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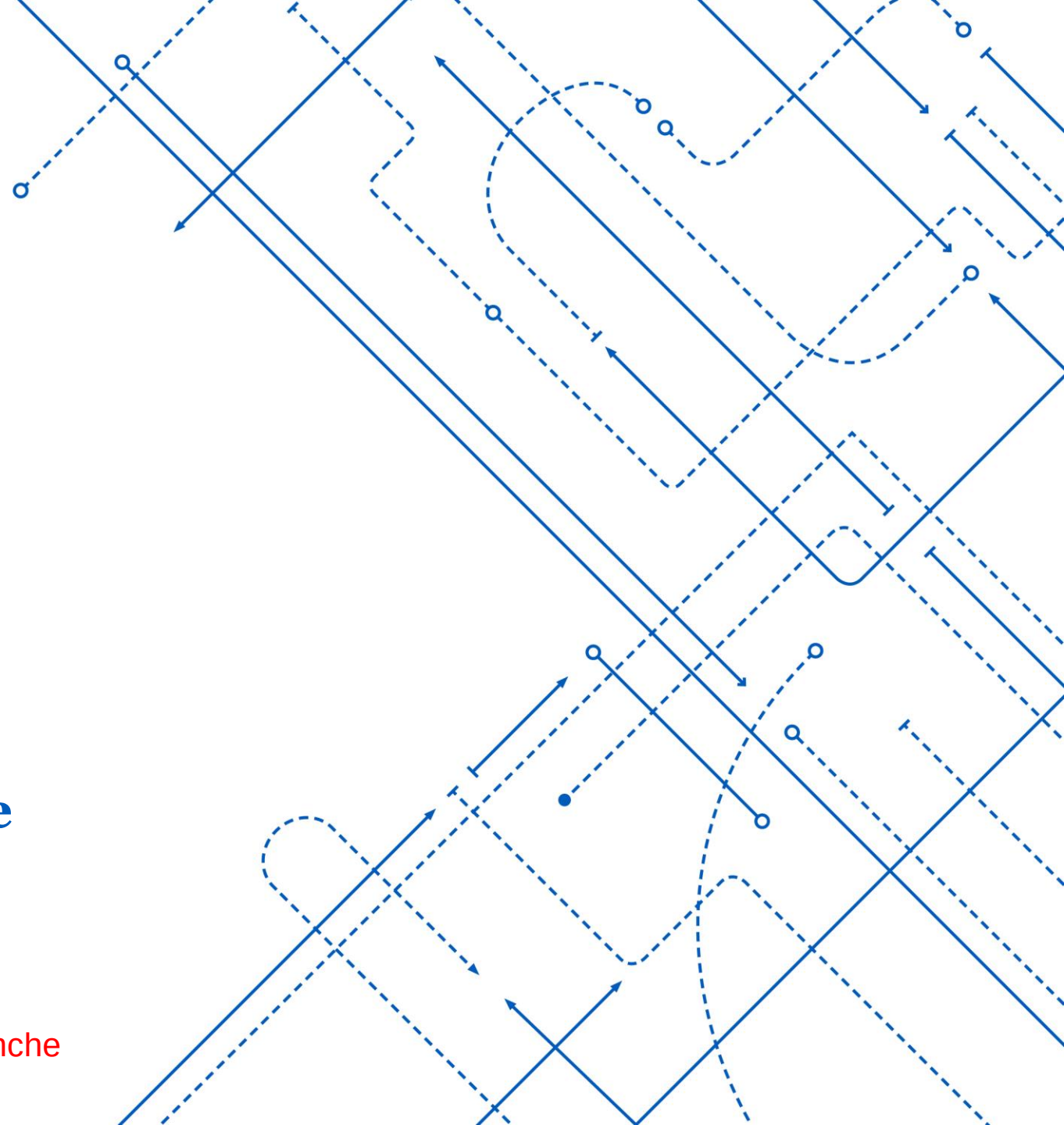
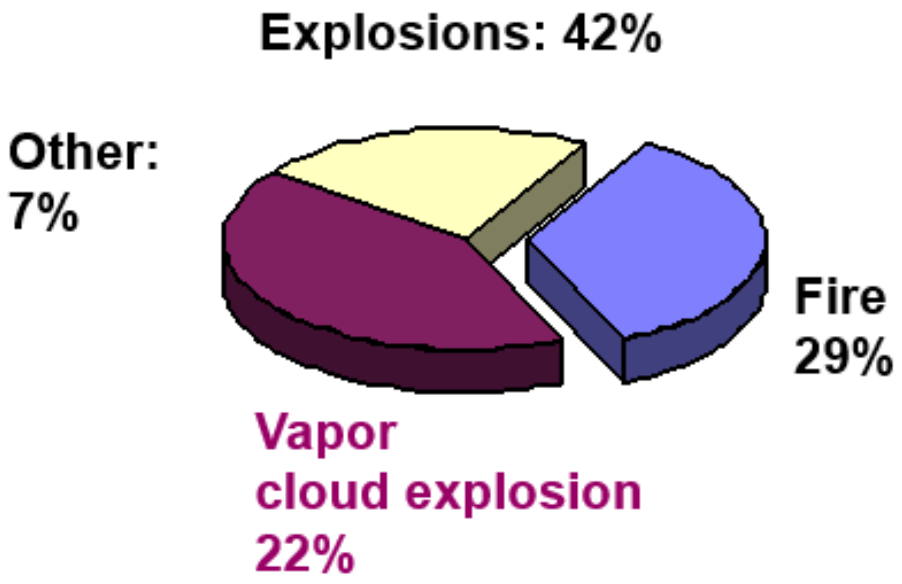


Fires and Explosions

Evaluation of the largest chemical plant accidents:



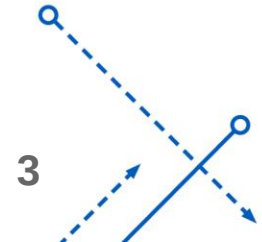
Most of the large accidents are due to fires and explosions.

Combustion Reaction

- Fire is an exothermic chemical reaction
- If the reaction goes to completion it is:

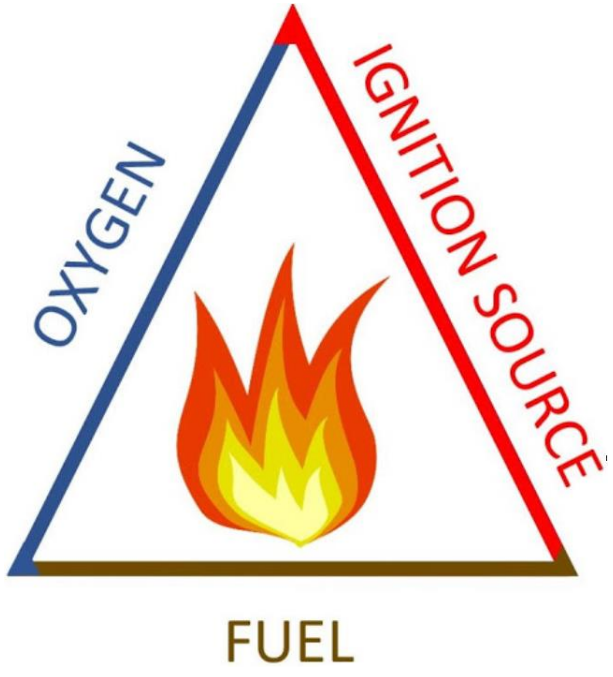
$$C_nH_{2n+2} + \frac{3n+1}{2} O_2 \rightarrow n\,CO_2 + (n+1)H_2O + Heat$$

- Of course, the fuel is not always a straight chain hydrocarbon as indicated in the equation above
  - Presence of nitrogen in fuel and air leads to NO_x
  - Presence of sulfur in fuel leads to SO_x
  - Other atoms lead to other entities
- Reaction usually does not go to completion leading to CO and smoke



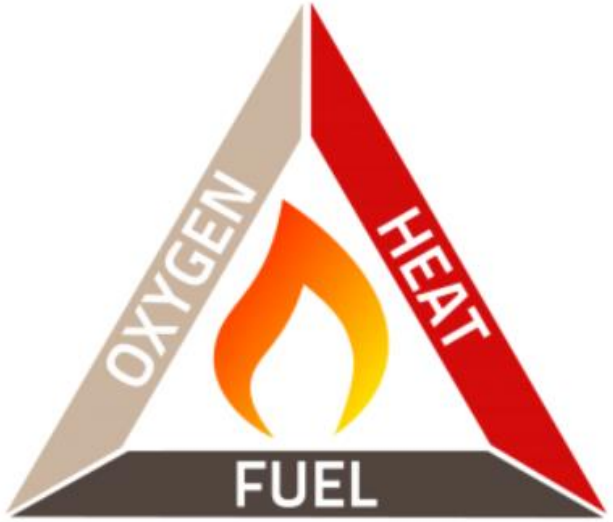
Fire Triangle

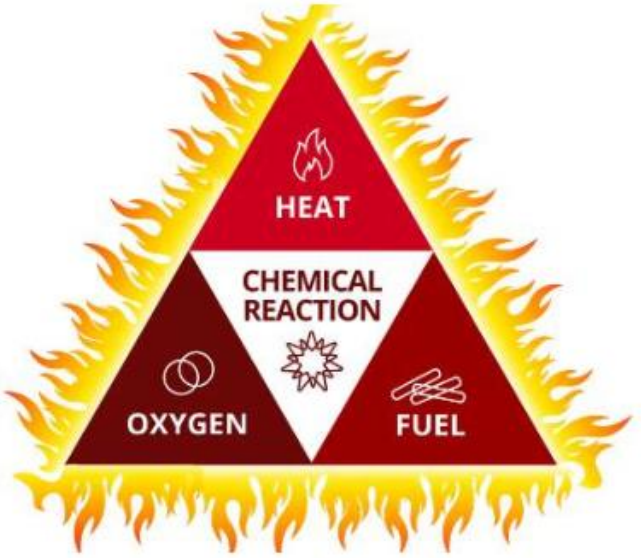
- In order for the combustion reaction to take place you need three elements, the fire triangle
- This depiction of the fire triangle deals with the initiation of the reaction
- For a fire to sustain it needs to be a continuing chain reaction



Sustained Combustion

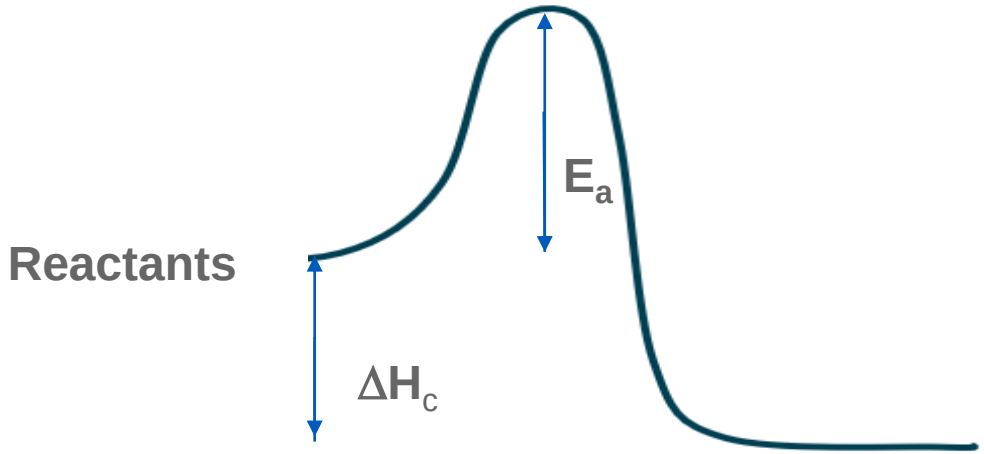
- In this version we see ignition replaced by heat
  - This is reflected in the fact that we can put out a fire by cooling it down

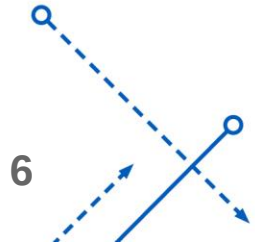




Ignition vs Heat on Fire Triangle

- The slide with ignition (as opposed to heat) shown as a side of the triangle recognizes that the activation energy for the combustion reaction of most fuels is fairly high. *(Initiating combustion)*
  - It is very unlikely that conditions will be hot enough to overcome heat of activation
  - A spark can supply that, as it has a temperature of thousands of degrees C
- Using the heat side recognizes that by lowering temperature the reaction kinetics can be slowed enough that the chain reaction is not sustained. Heat can be dissipated. *(Sustaining combustion)*
- Some select materials do have a low autoignition temperature and would not need a spark
  - Autoignition temperature is the temperature where the material will self ignite without a spark

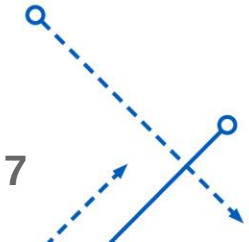




Fire versus Explosion

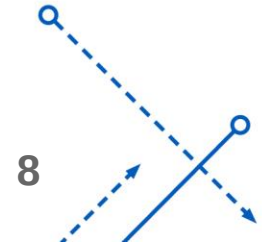
- In a nutshell:

Explosions lead to rapid release of energy causing pressure waves



Various Definitions

- Combustion or fire – chemical reaction where a substance combines with an oxidant and releases energy. Part of the energy is used to sustain the reaction
- Ignition – a flammable mixture comes in contact with energy source or reaches a high enough temperature to autoignite and commences the combustion reaction
- Flash point – the lowest temperature where a liquid will have sufficient vapor pressure to generate an ignitable mixture with the air above it

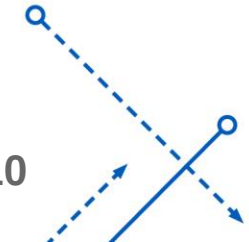


Various Definitions

- Flammability Limits – like most chemical reactions, combustion requires a limited range of reactant (fuel and oxidant) ratio in order to ignite and burn. Flammability limits are specific to the given material
- Lower Flammability Limit (LFL) or Lower Explosion Limit (LEL)
  - If there is not enough fuel the fuel molecules are not close enough together to sustain the chain reaction
- Upper Flammability Limit (UFL) or Upper Explosion Limit (UEL)
  - If there is too much fuel the oxygen molecules are not close enough together to sustain the chain reaction
- Note that the flammability limits as listed are typically experimental and are measured at a certain temperature and pressure

Various Definitions

- Explosion – rapid expansion of gases resulting in a rapidly moving pressure or shock wave
- Mechanical Explosion – a vessel containing pressurized gas fails and releases rapidly expanding gas. No chemical reaction occurs
- Deflagration – explosion where reaction front moves at less than the speed of sound in the unreacted medium
- Detonation - explosion where reaction front moves at greater than the speed of sound in the unreacted medium



Various Definitions

- Confined Explosion – explosion within a vessel or building
- Unconfined Explosion – explosion outdoors
  - Generally requires a very large release due to the dilution effect of wind dispersion
- Boiling-Liquid-Expanding-Vapor-Explosion (BLEVE)
  - External fire heats contents of vessel above it normal boiling point
  - Contents remain in liquid phase due to increased internal pressure
  - Vessel fails due to high temperature and pressure
  - Now the liquid rapidly vaporizes and expands causing pressure wave
  - If vapor is combustible and ignites it is that much worse

Fires and Explosions

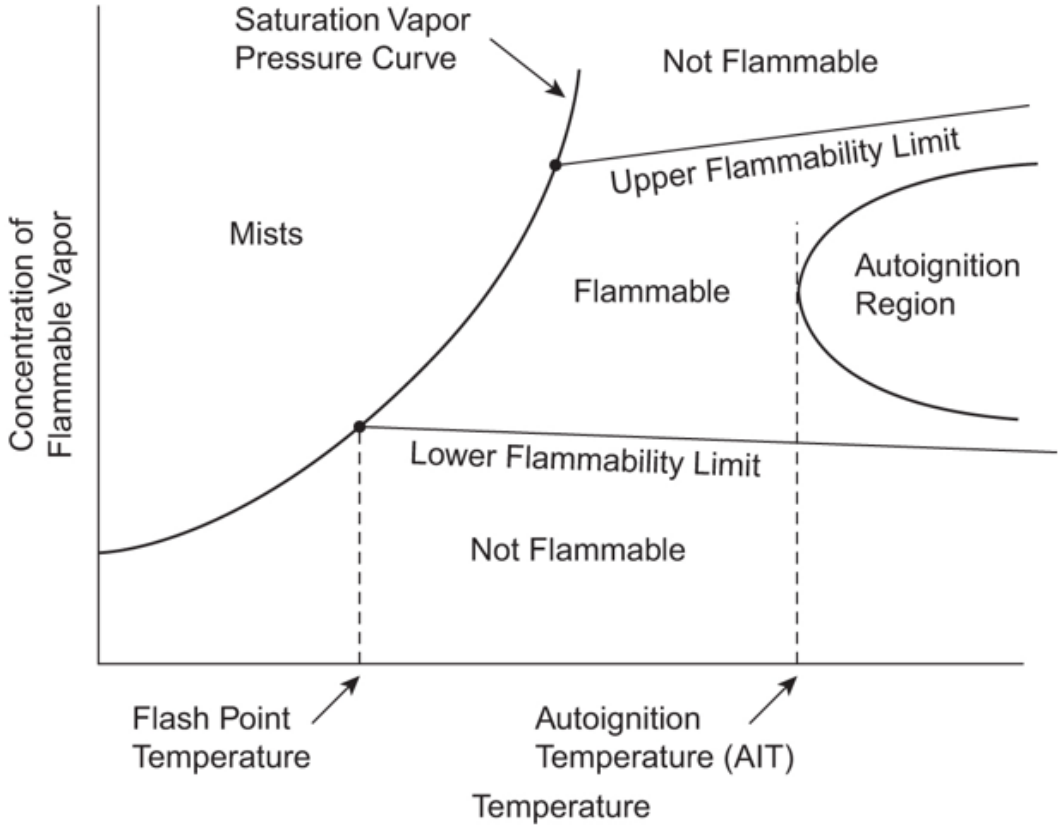


Figure 6-2 Relationships between various flammability parameters.

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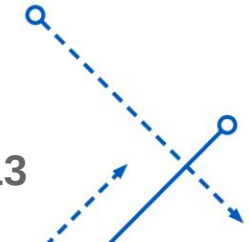
Fires and Explosions

- Note the region on the previous slide labeled **mists**
  - This means that the fuel is in droplet form
  - Depending on the droplet size and concentration this can be very flammable
  - Mists have the added hazard that the droplets are separated from one another and any source of grounding and can therefore develop static charge
  - If the static build up discharges we have an ignition source



Fires and Explosions

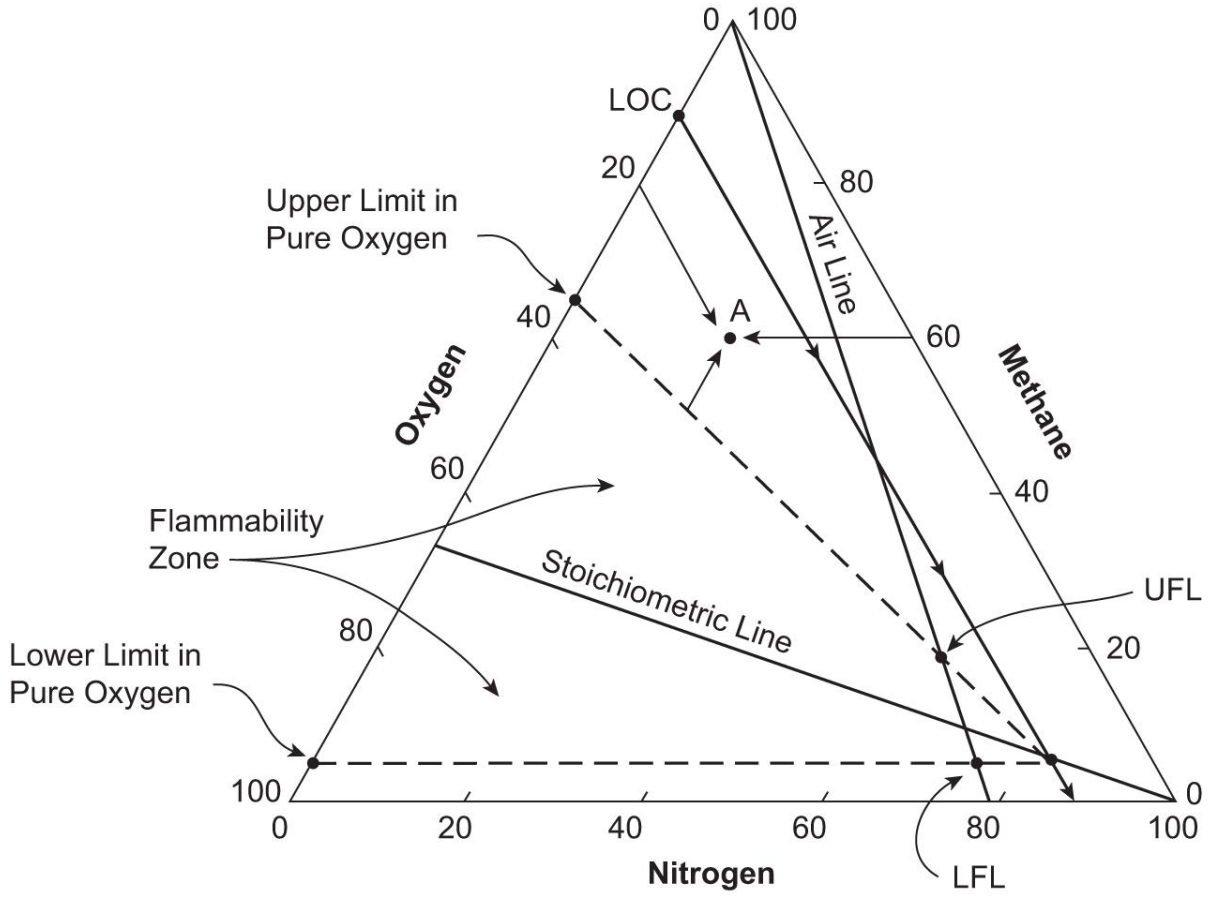


Figure 6-5 Flammability diagram for methane at an initial temperature and pressure of 25°C and 1 atm. (Source: C. V. Mashuga and D. A. Crowl. "Application of the Flammability Diagram for Evaluation of Fire and Explosion Hazards of Flammable Vapors," Process Safety Progress, Vol. 17, No. 3, 1998, pp 176–183.)

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Estimating Flash Points

- Textbook shows a method for estimating flash point
  - Flash points are fairly easy to experimentally measure
  - I recommend against estimating them
- Send samples to a test lab instead!

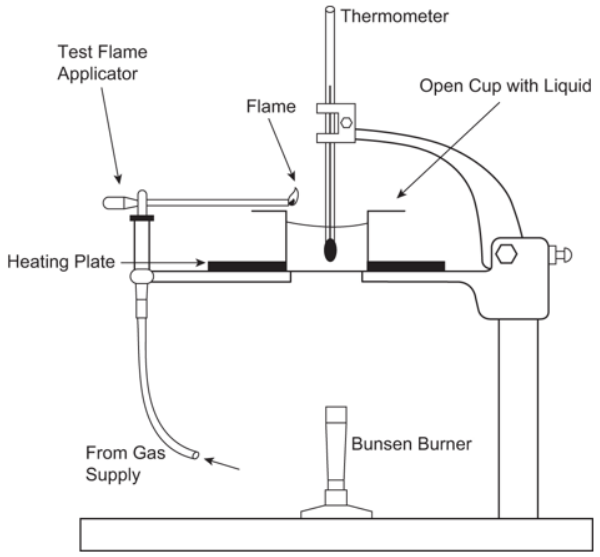

Figure 6-3 Cleveland open-cup flash point determination. The test flame applicator is moved back and forth horizontally over the liquid sample.

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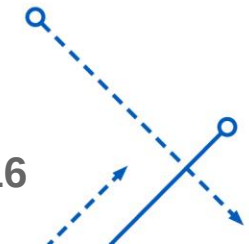
Combustible Vapor Mixtures

- If we have data for each component we can estimate flammability limits for mixture with Le Chatelier equation:

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

Where

- LFL_i and UFL_i are the flammability limits of component i (in volume %) of component i in fuel and air
- y_i is the mole fraction of component i relative to just the combustible components
- n is the number of components



Estimation of Pressure and Temperature Effects

- Textbook has some correlations and warns they are limited to a specific range
- This is too important to use estimations – ***GET EXPERIMENTAL DATA!***