# Chemical Process Safety
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## Indian Institute of Technology Roorkee
## Lectures 22 - Fire & Explosion: Flammability Characteristics

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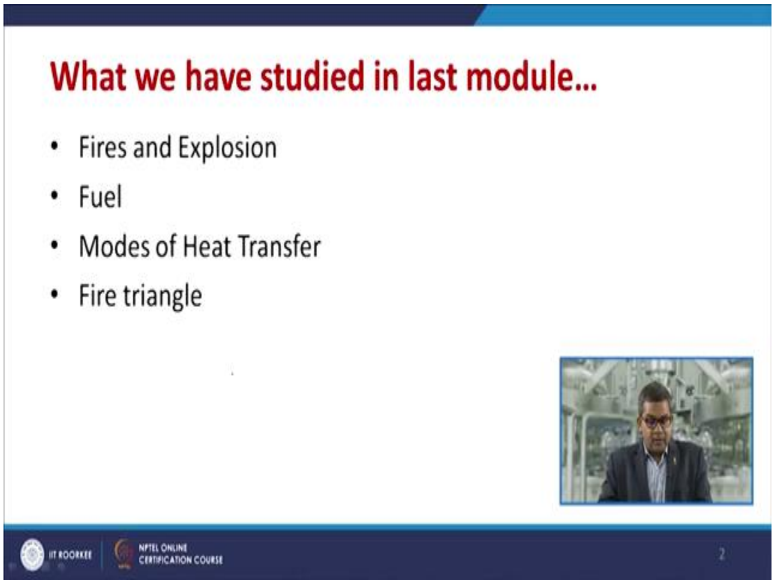

What we have studied in last module...

- Fires and Explosion
- Fuel
- Modes of Heat Transfer
- Fire triangle

Welcome to the second module of fire and explosion. Up till now we have studied about the fire and explosion, the basic definition of fire and explosion, different type of fuels which are responsible for fire, we have discussed about the different mode of heat transfer through which fire or heat generated being transmitted to some other part and we discussed about the fire triangle which is responsible for fire propagation, initiation etc.

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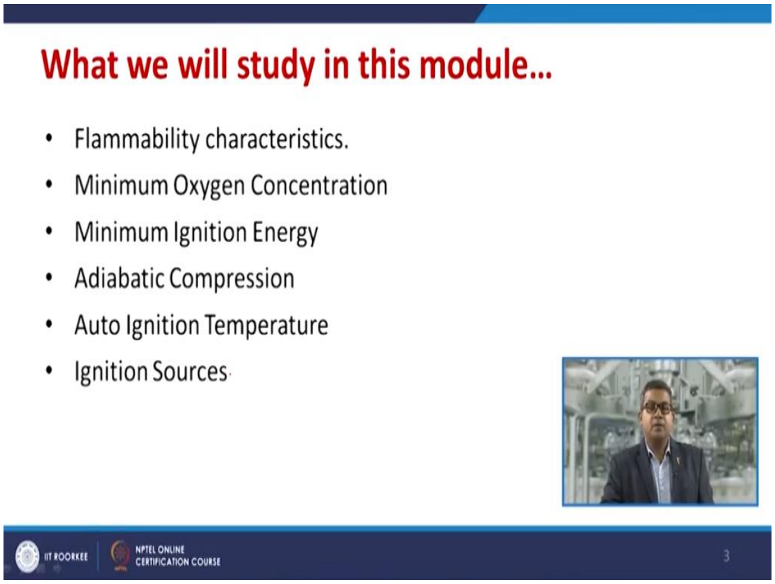

## What we will study in this module…

- Flammability characteristics.
- Minimum Oxygen Concentration
- Minimum Ignition Energy
- Adiabatic Compression
- Auto Ignition Temperature
- Ignition Sources

Now in this module we will discuss about the flammability characteristics which is extremely important that how, what are the different parameters required for flammability, minimum oxygen concentration, minimum ignition energy, adiabatic compression, auto-ignition temperature and various sources of ignition.

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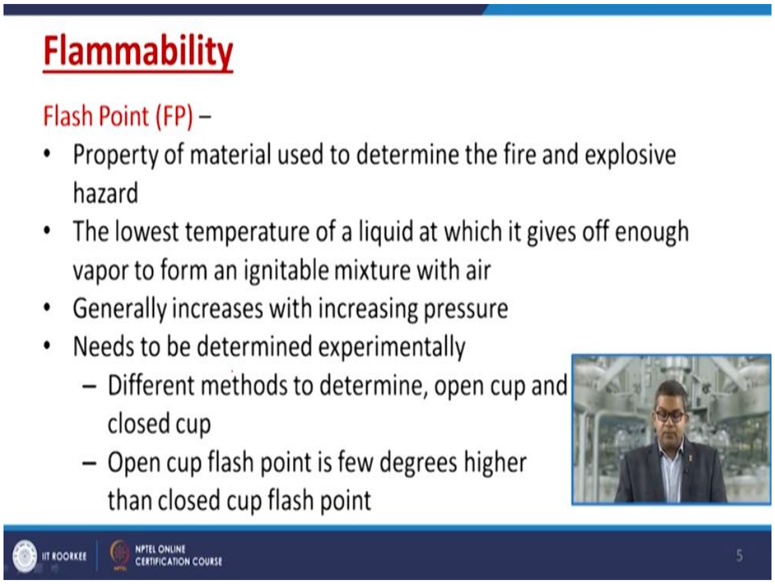

## Flammability

Flash Point (FP) –

- Property of material used to determine the fire and explosive hazard
- The lowest temperature of a liquid at which it gives off enough vapor to form an ignitable mixture with air
- Generally increases with increasing pressure
- Needs to be determined experimentally
  - Different methods to determine, open cup and closed cup
  - Open cup flash point is few degrees higher than closed cup flash point

Now flammability characteristics. Before we discuss the flammability characteristics lets have a look about the flash point. Now flash point, this is a property of a material used to determine the fire and explosive hazard, this is the lowest temperature of a liquid at which it gives off enough vapor to form an ignitable mixture with air. So whenever there is an ignitable mixture there are another criteria which needs to be fulfilled before any particular flammable mixture caches fire. We will discuss in the subsequent slide.

Now generally this flash point increases with increasing pressure and it needs to be determined experimentally. Now there are different method for determination of flash point like open cup, closed cup. Now open cup flash point is few degree higher than the closed cup flash point and one point should be remembered that whenever we report the flash point then it must be reported that through which method it was determined.

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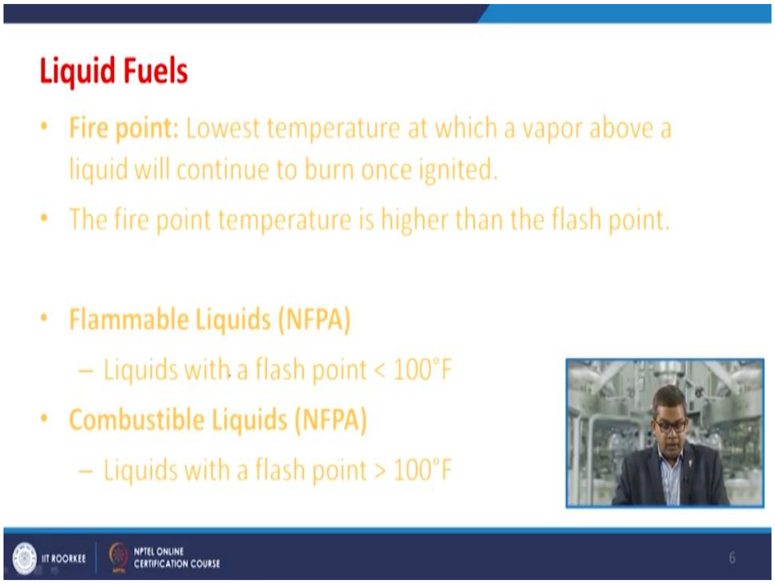

## Liquid Fuels

- **Fire point:** Lowest temperature at which a vapor above a liquid will continue to burn once ignited.
- The fire point temperature is higher than the flash point.
- **Flammable Liquids (NFPA)**
  - – Liquids with a flash point < 100°F
- **Combustible Liquids (NFPA)**
  - – Liquids with a flash point > 100°F

As far as liquid fuels are concerned, another point is fire point. This is the lowest temperature at which a vapor above liquid will continue to burn once ignited. The fire temperature is higher than the flash point temperature. There are certain other things which are proposed by national fire protecting agency, United States about the flammable liquid, the liquid which with a flash point less than 100 degree Fahrenheit. Now this type of characterization is essential whenever we need to design the protective equipments. We need to design the fire retardancy aspect of any process, then we must know that which liquid is flammable and which is not.

Then combustible liquid, the liquid with flash point greater than 100 degree Fahrenheit. Now let us have a look about the flammability limit. We must know that which is the flammable mixture, which mixture can combust. So far when mixture is having the higher concentration then definitely the corresponding amount of oxygen would be on the lower side, then definitely the mixture would not be ignitable. So question arises that, what are the limit and how we can ignite the combustible mixture?

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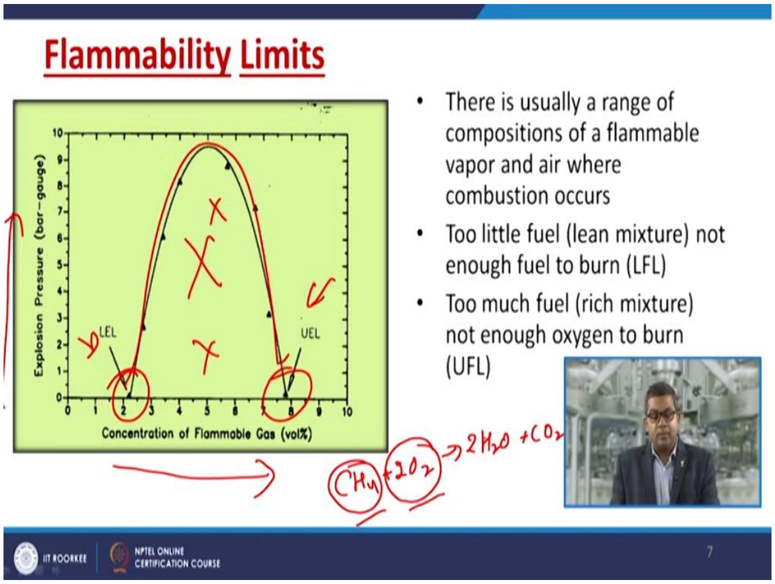

**Flammability Limits**

- There is usually a range of compositions of a flammable vapor and air where combustion occurs
- Too little fuel (lean mixture) not enough fuel to burn (LFL)
- Too much fuel (rich mixture) not enough oxygen to burn (UFL)

$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

So people have proposed 2 types of limit, lower flammability limit and upper flammability limit, so there is a usually range of composition of a flammable vapor and air where the combustion occurs. Now the one thing must be remembered that for any kind of flammability, any kind of formation of combustible mixture, there must be a fulfillment of stoichiometric demand. Let us have a hydrocarbon combustion formula

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

now once these two things with methane and oxygen they are in the stoichiometric demand, only then the fire will catch. So in other words if there is a too little fuel and which is not enough for to burn, that is covered under the head of lower flammability limit.

And if too much fuel, that means the fuel concentration is on the extremely higher side and which is not duly supported by the supply of oxygen, then again there would be a difficulty in fire. So in this particular plot we can see the concentration of flammable gases in volume percent and explosion pressure. So this is, these 2 are lower explosive limit, this 1 and upper explosive limit. Sometimes LFL and UFL they are called lower explosive limit and upper explosive limit, so whatever is inside this plot that is the combustible, we will discuss in the subsequent slides in detail.

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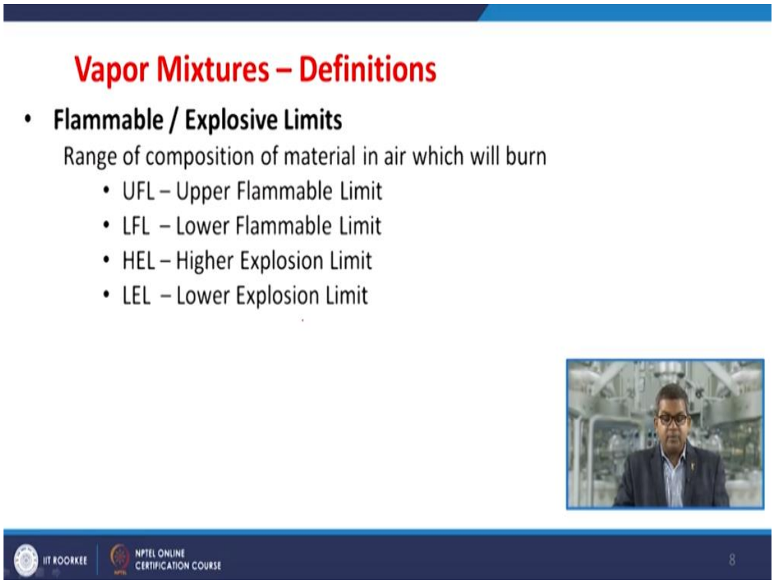

## Vapor Mixtures – Definitions

- **Flammable / Explosive Limits**

  Range of composition of material in air which will burn
  - UFL – Upper Flammable Limit
  - LFL – Lower Flammable Limit
  - HEL – Higher Explosion Limit
  - LEL – Lower Explosion Limit

Now the flammable and the explosive limits, the range of composition of material in air which will burn, that is upper flammable limit, lower flammability limit, sometimes it is termed as higher explosive limit and lower explosive limit.

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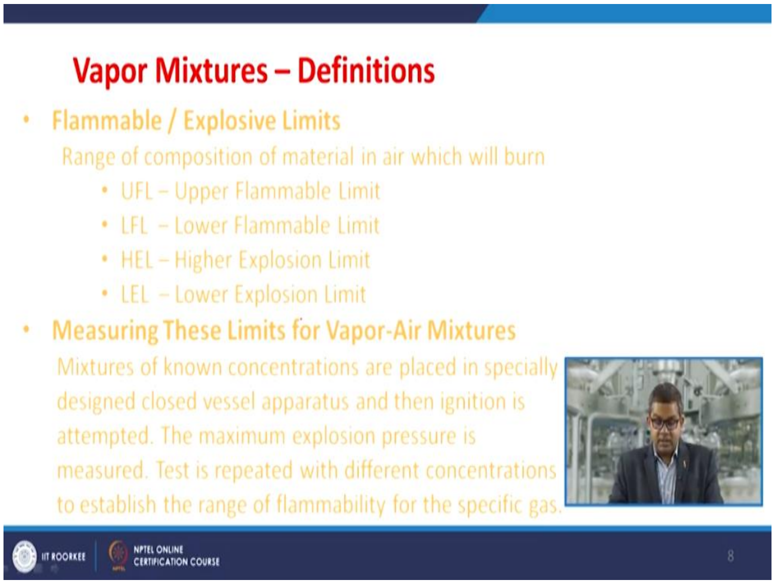

## Vapor Mixtures – Definitions

- **Flammable / Explosive Limits**

  Range of composition of material in air which will burn
  - UFL – Upper Flammable Limit
  - LFL – Lower Flammable Limit
  - HEL – Higher Explosion Limit
  - LEL – Lower Explosion Limit
- **Measuring These Limits for Vapor-Air Mixtures**

  Mixtures of known concentrations are placed in specially designed closed vessel apparatus and then ignition is attempted. The maximum explosion pressure is measured. Test is repeated with different concentrations to establish the range of flammability for the specific gas.

Now measuring these limits for vapor air mixture, mixture of known concentration are placed in specially designed closed vessel apparatus and then ignition is attempted. The maximum explosion pressure is measured, now usually test is repeated with different concentration to establish the range of flammability for the specific gas.

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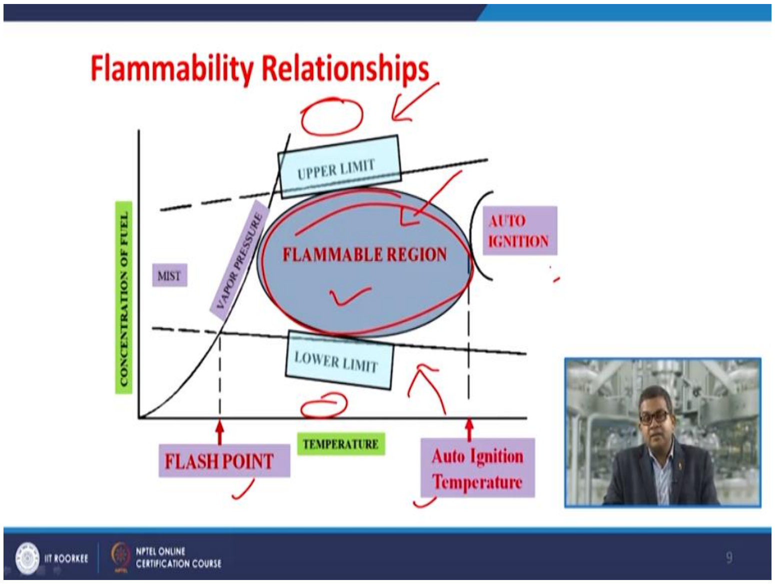

Flammability Relationships

Because sometimes it is advisable that you must not able to form this type of mixture within this LFL and UFL. So if you wish to work in safer range, then you need to have your mixture either in this range or in this range because this range is a flammability region. Somehow if by any source it catches the source of ignition then definitely there are chances that it will ignite. So if you wish the fire to be placed there, then deliberate attempt, then your mixture should be in this range. And if you do not wish then definitely you have to take certain attempts so that the mixture does not fall in this flammability region.

Now whenever we wish to form any kind of flammability relationship or flammability chart, we should not forget the importance of flash point, auto-ignition temperature etc, because sometimes if your mixture is beyond this range and by any means it acquires sufficient amount of energy then it will automatically auto-ignite and then the things would be more dangerous compared to the previous one. So whenever you wish to form or we are having any hydrocarbon or any flammable liquid or flammable gas with you, then it is important that you need to know that what is my LFL, what is my UFL and what is a flash point and auto-ignition temperature.

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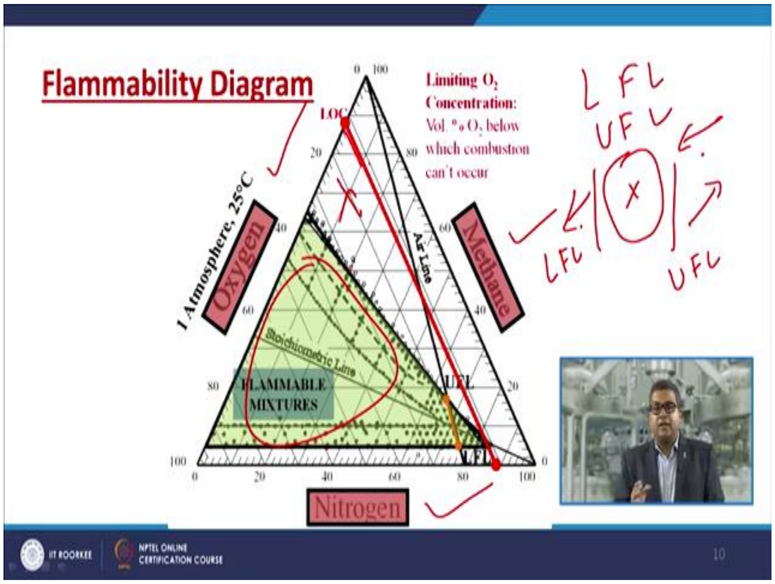

Flammability Diagram

Limiting $O_2$ Concentration: Vol. % $O_2$ below which combustion can't occur

Sometimes it is again equally important to form the different type of flammability diagram so that you can have the flammability mixture line. Now here you can find this particular diagram is very interesting, the reason is that you are having one fuel, you are having one oxidizer. Apart from this you are having an inert. Now question arises that, why do we use inert? The reason is that we having LFL and UFL in place, that means and suppose I am working in a hexane environment.

So definitely we do not want to have combustible mixture that is the combination of hexane vapor plus oxygen and somehow because if by any means you are not in a position to avoid such kind of mixture, then definitely your attempt should be like this that you must introduce some inert so that it fall either with, either it goes lower to the LFL limit so that this mixture does not in place or somehow if you wish to increase or if you are in a position to increase the supply of fuel, so you enrich the combustible mixture in such a way that the concentration of methane is on the higher side.

But remember this particular aspect is extremely dangerous, the reason is that if by any chance or by any leaking sufficient quantity of oxygen or air is entrapped within the zone, then definitely it will form a combustible mixture. So you must know that how much quantity of inert material is required to make the things safer, for this these type of diagrams are quite beneficial. Now this is the particular diagram for the methane, here you must, this particular region is the flammability, flammable region. Now here you can assess that what should be the, at what concentration of methane and at what concentration of oxygen because you can see the stoichiometric line, so your attempt should be like this that you must introduce nitrogen in such a way so that it does not cross the LFL mark.

So this is another line that is depicting the limiting oxygen concentration, the limiting oxygen concentration it says that the volume percent of oxygen below which combustion cannot occur. That means there is no adequate supply of oxygen to meet the stoichiometric demand. If you recall the previous chemistry formula for $CH_4 + 2O_2$, that means if you are increasing the amount of nitrogen that means definitely it will not cross this limiting oxygen concentration mark, now this is a safer zone.

So that is why whenever you are having such type of scenario, you must calculate that up to how much quantity of inert material is required so that it does not cross this LOC barrier or it does not cross the LFL line.

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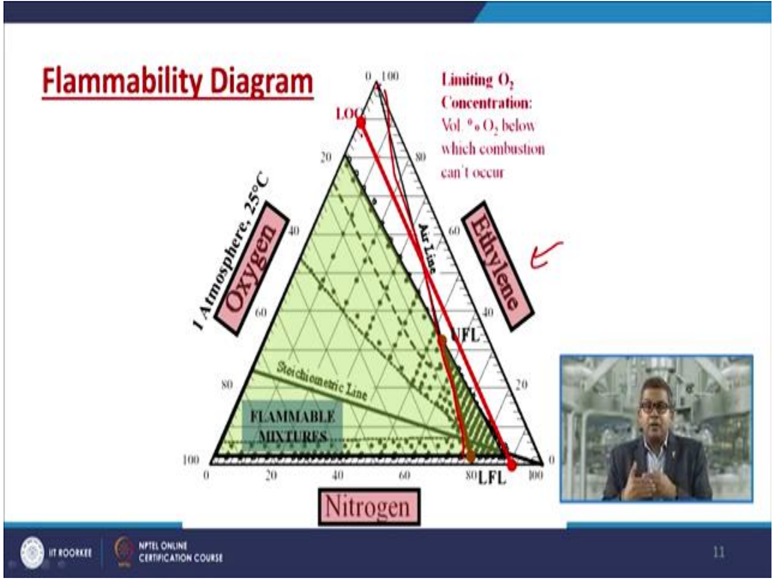

Flammability Diagram

Limiting $O_2$ Concentration: Vol. % $O_2$ below which combustion can't occur

This is again for the ethylene, ethylene hydrocarbon again, sorry, now here again you can see the LOC and this is our air line that means a supply of air. Oxygen is automatically being extracted from the air, so ethylene the combustion of ethylene requires this quantity of oxygen.

So by any means of introduction of nitrogen if you introduce certain quantity of nitrogen, that means the concentration of oxygen or limiting oxygen concentration is on the lower side or the LFL is on the lower side so that the mixture does not form the combustible one. Now question arises that once we have discussed the flammability limit, what are the parameters those who are affecting these flammability limits?

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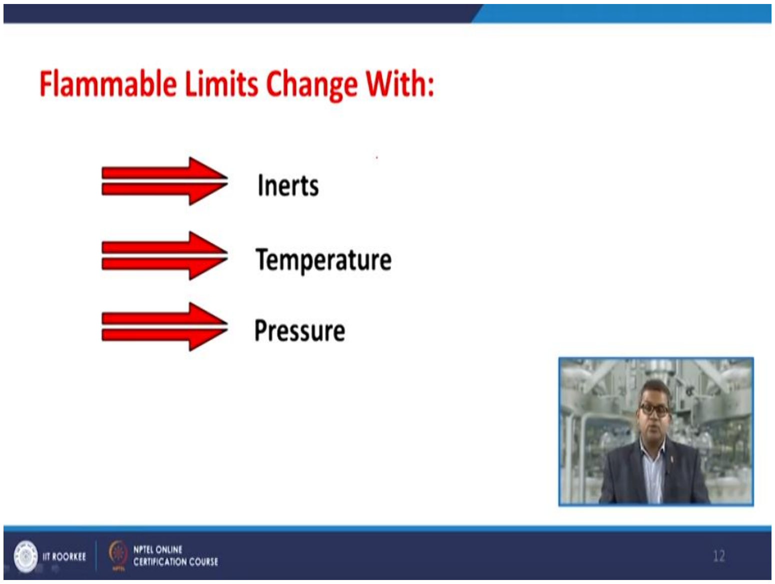

## Flammable Limits Change With:

- Inerts
- Temperature
- Pressure

So there are 3 different parameters, that is a concentration of inert material we have discussed through two diagrams, the temperature and the pressure, so these 3 are the measure parameters those who are affecting the flammability limits.

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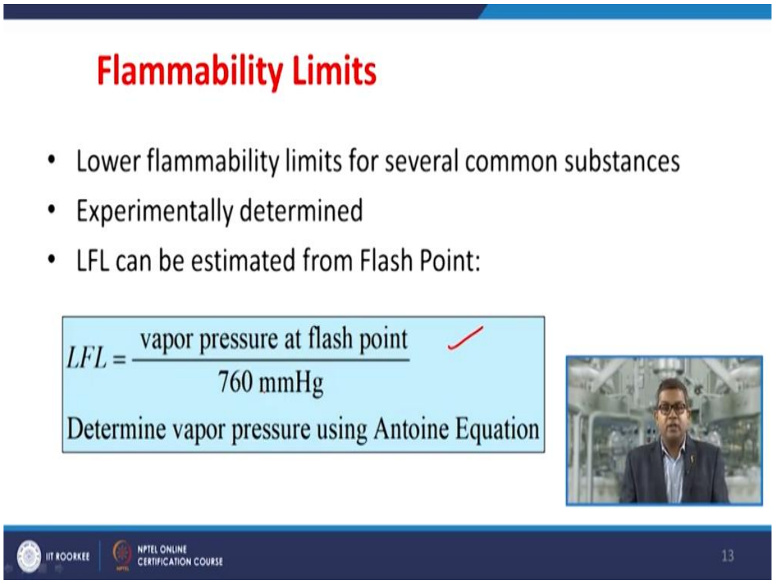

## Flammability Limits

- Lower flammability limits for several common substances
- Experimentally determined
- LFL can be estimated from Flash Point:

$$LFL = \frac{\text{vapor pressure at flash point}}{760\ \text{mmHg}}$$

Determine vapor pressure using Antoine Equation

Now let us have a look that how this LFL is determined and what are the different mathematical equations applied for, to govern this LFL. So lower flammability limits for several common substances we need to determine and usually it is advisable to determine those limits through experimental process. However, if you have adequate knowledge of flash point then LFL you can be estimated through the flash point. Now here is the formula that LFL equal to vapor pressure at flash point divided by 760 mm mercury, so determination of a vapor pressure using the Antoine equation, Antoine equation is a very famous equation in chemical thermodynamics. So you can determine the vapor pressure through which you can assess that what will be the theoretical LFL of that particular substance.

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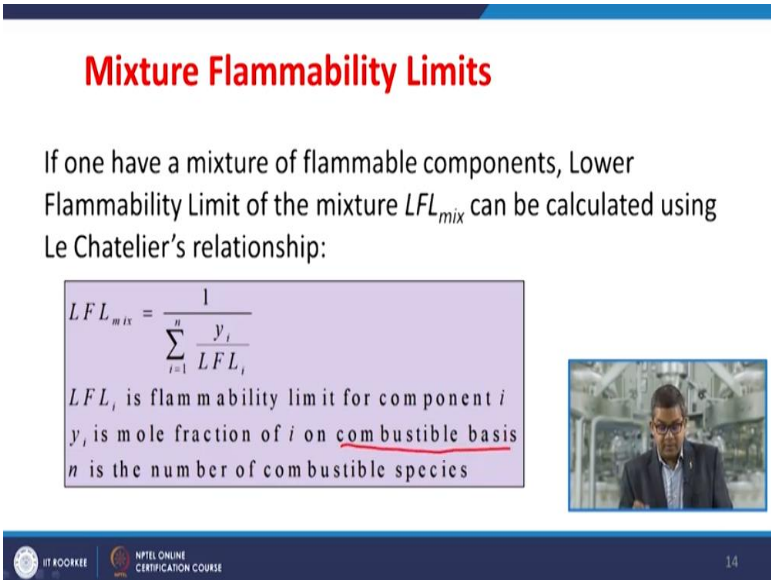

Mixture Flammability Limits

If one have a mixture of flammable components, Lower Flammability Limit of the mixture $LFL_{mix}$ can be calculated using Le Chatelier's relationship:

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

$LFL_i$ is flammability limit for component $i$

$y_i$ is mole fraction of $i$ on combustible basis

$n$ is the number of combustible species

Now if one have a mixture of flammability components, lower flammability limit or LFL mixture can be calculated using the Le Chatelier's relationship. Now this Le Chatelier's relationship is there,

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

This $LFL_i$ is a flammability limit for component i and $y_i$ is the mole fraction of ith component on combustible basis. Remember, this particular combustible basis because inert material you cannot take into consideration. And n is the number of combustible species present in that particular mixture.

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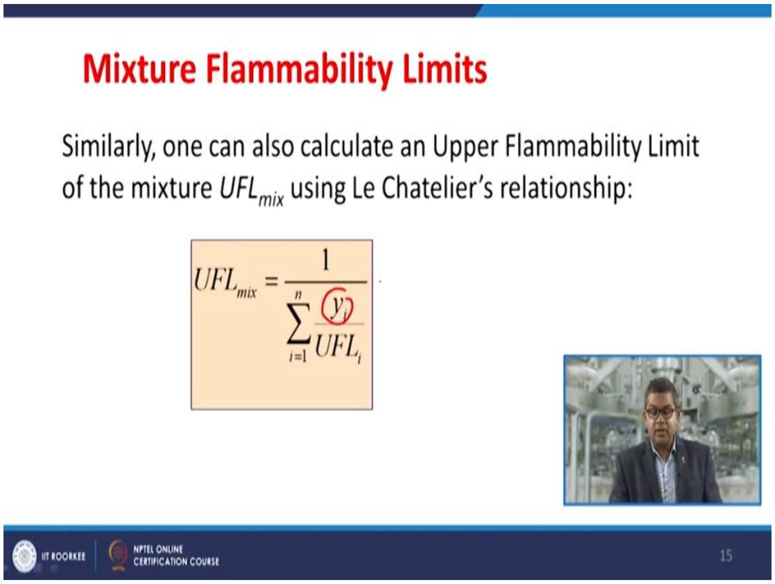

## Mixture Flammability Limits

Similarly, one can also calculate an Upper Flammability Limit of the mixture $UFL_{mix}$ using Le Chatelier's relationship:

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

Similarly, you can calculate the upper flammability too for the mixture using again the same Le Chatelier's relationship,

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

Other designation like this is the mole fraction, ith component and on the combustible basis.

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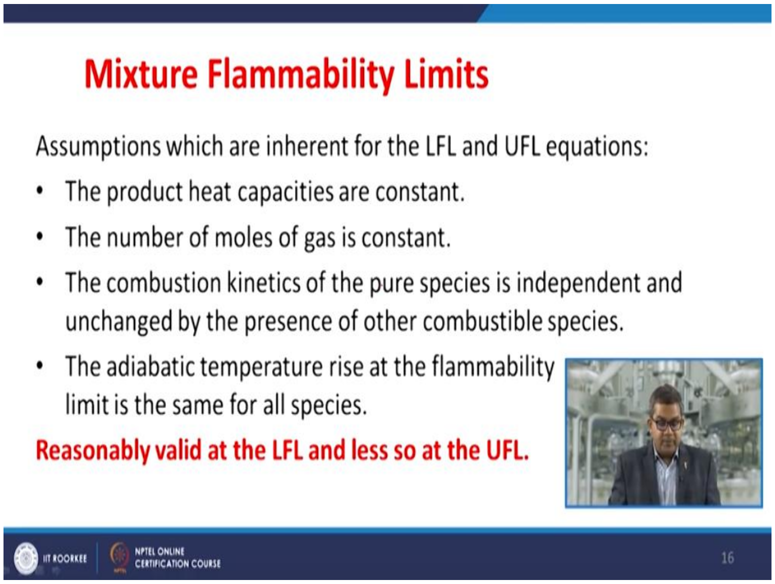

## Mixture Flammability Limits

Assumptions which are inherent for the LFL and UFL equations:

- The product heat capacities are constant.
- The number of moles of gas is constant.
- The combustion kinetics of the pure species is independent and unchanged by the presence of other combustible species.
- The adiabatic temperature rise at the flammability limit is the same for all species.

**Reasonably valid at the LFL and less so at the UFL.**

Now for determination of these LFL and UFL there are certain inherent assumptions we have taken, the inherent assumptions though they are theoretical one but still we cannot overlook their importance. The product heat capacity is our constant though I cannot say precisely because the temperature is on the varying side. The number of moles of gas is assumed to be the constant, the combustion kinetics of pure species is independent and unchanged by the presence of other combustible species.

The adiabatic temperature rise at the flammability limit, is the same for all species reasonably valid at LFL and less so that of UFL, so because the temperature variance and mole they do effect in the determination of LFL and UFL, so earlier slides we have discussed that the LFL and UFL both are having impacted by temperature.

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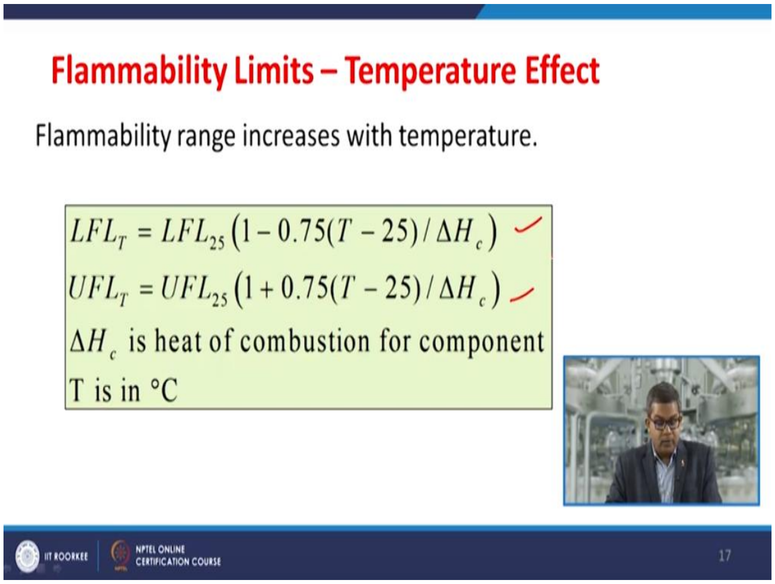

**Flammability Limits – Temperature Effect**

Flammability range increases with temperature.

$LFL_T = LFL_{25}\left(1 - 0.75(T - 25)/\Delta H_c\right)$

$UFL_T = UFL_{25}\left(1 + 0.75(T - 25)/\Delta H_c\right)$

$\Delta H_c$ is heat of combustion for component

T is in °C

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17

Now these are the formula through which you can assess the effect of temperature on LFL and UFL and usually the standard denotation of or standard representation of LFL and UFL is 25 degree Celsius. So if you wish to determine the LFL UFL, let us say 80 degree Celsius or 90 degree Celsius, then you can easily utilize these 2 formula,

$$LFL_T = LFL_{25}\left(1 - \frac{0.75(T - 25)}{\Delta H_c}\right)$$

$$UFL_T = UFL_{25}\left(1 + \frac{0.75(T - 25)}{\Delta H_c}\right)$$

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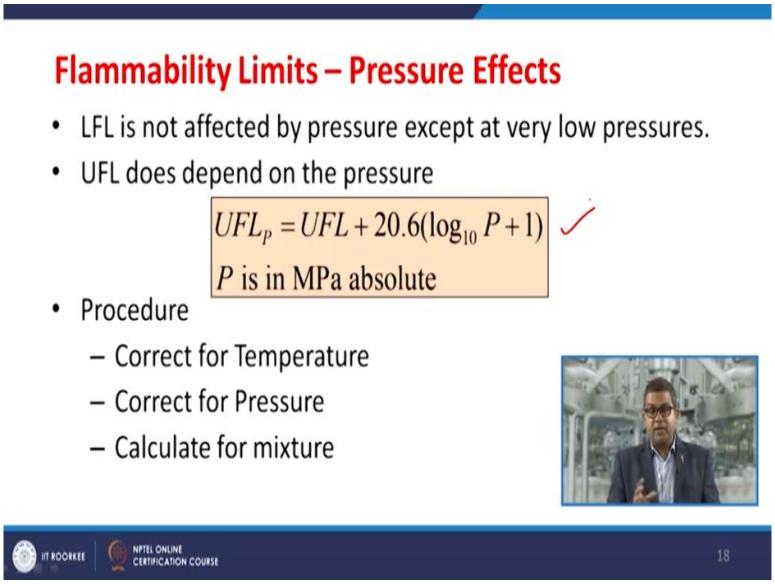

## Flammability Limits – Pressure Effects

- LFL is not affected by pressure except at very low pressures.
- UFL does depend on the pressure

$$\boxed{\begin{array}{l} UFL_P = UFL + 20.6(\log_{10} P + 1) \\ P \text{ is in MPa absolute} \end{array}} \checkmark$$

- Procedure
  - Correct for Temperature
  - Correct for Pressure
  - Calculate for mixture

Now theoretically you can determine all this LFL and UFL so that you can anticipate that suppose if I wish to run the reaction at say 120 degree Celsius then definitely it is my first right to know that what would be the LFL and UFL at the specified temperature at my working temperature. So these formula or these mathematical relationships, they are quite useful, now the last effect is the flammability limit, the pressure effect. Now LFL is usually not affected by pressure except a very low pressure and usually at very low pressure the chances of ignition are very rare.

So UFL does depend on the pressure and this is the mathematical relationship through which you can predict the pressure of pressure effect on UFL at particular point of time. So,

$$UFL_P = UFL + 20.6\ (\log_{10} P + 1)$$

So the procedure is to correct for the temperature prima facie then the correct for pressure and then calculate for the mixture. So you are having the wide spectrum through which you can assess that what would be LFL and UFL of the mixture and individual component.

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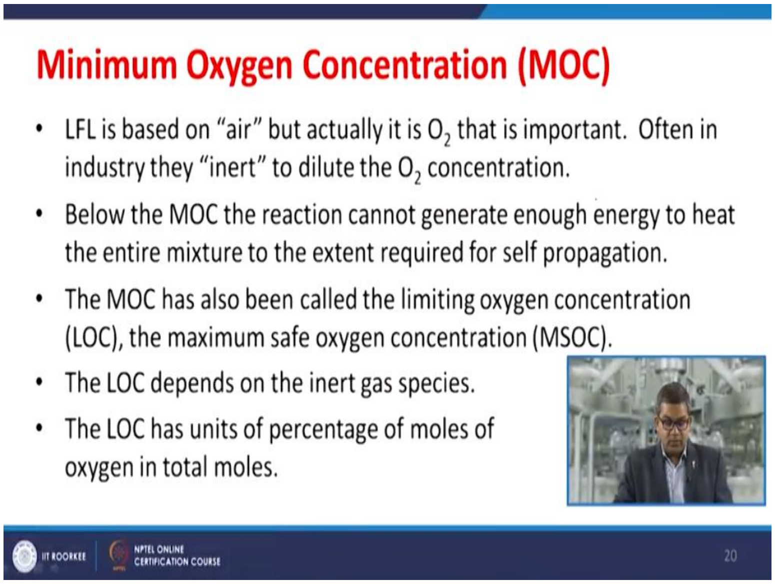

## Minimum Oxygen Concentration (MOC)

- LFL is based on "air" but actually it is $O_2$ that is important. Often in industry they "inert" to dilute the $O_2$ concentration.
- Below the MOC the reaction cannot generate enough energy to heat the entire mixture to the extent required for self propagation.
- The MOC has also been called the limiting oxygen concentration (LOC), the maximum safe oxygen concentration (MSOC).
- The LOC depends on the inert gas species.
- The LOC has units of percentage of moles of oxygen in total moles.

Now let us have a look about the minimum oxygen concentration, see we talked about this importance of oxygen in the previous slides that the mixture or fuel must be in stoichiometric presence so that it can catches the fire. That means you require a minimum oxygen for any kind ignition for any kind of fire, so LFL is based on air but actually it is oxygen that is important. Often, it is industry they inert to dilute the oxygen concentration so that it is just below the LFL range, so below the minimum oxygen concentration the reaction cannot generate enough energy.

So that it cannot beat the requirement of $\Delta H_c$ to heat the entire mixture of to the extent required for self-propagation. The MOC in previously has also been called the limiting oxygen concentration, the maximum safe oxygen concentration is MSOC. Sometimes you may find in literature that it is reported in terms of MSOC. So LOC depends on inert gas species, that is why if you recall in the previous slides that we have discussed the nitrogen, the effect of nitrogen those diagrams. So usually depends on inert gas species, the LOC has the unit of percentage of moles of oxygen in total moles.

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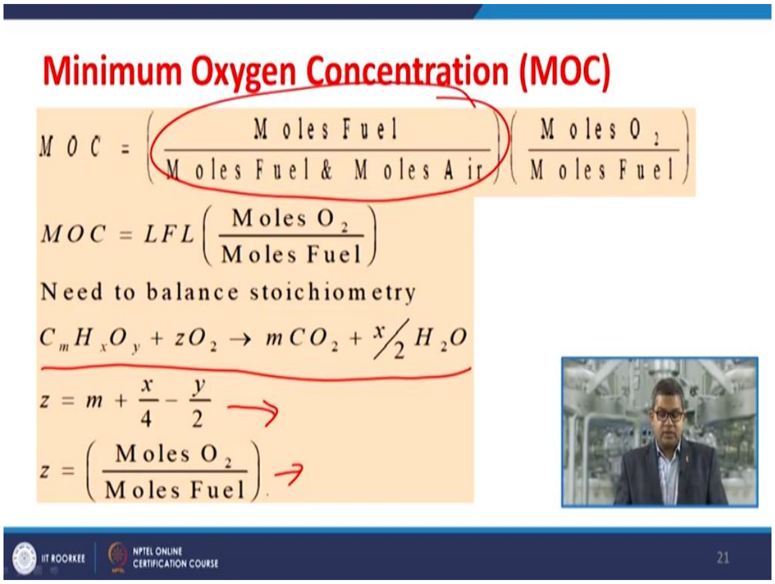

## Minimum Oxygen Concentration (MOC)

$$MOC = \left(\frac{\text{Moles Fuel}}{\text{Moles Fuel \& Moles Air}}\right)\left(\frac{\text{Moles O}_2}{\text{Moles Fuel}}\right)$$

$$MOC = LFL\left(\frac{\text{Moles O}_2}{\text{Moles Fuel}}\right)$$

Need to balance stoichiometry

$$C_mH_xO_y + zO_2 \rightarrow mCO_2 + {}^{x}\!/_{2}\,H_2O$$

$$z = m + \frac{x}{4} - \frac{y}{2}$$

$$z = \left(\frac{\text{Moles O}_2}{\text{Moles Fuel}}\right)$$

Now this is the mathematical relationship or derivation through which you can calculate theoretically the minimum oxygen concentration.

$$MOC = \left\{\frac{moles\ fuel}{moles\ fuel\ \&\ moles\ air}\right\}\left\{\frac{moles\ Oxygen}{moles\ fuel}\right\}$$

$$MOC = LFL\left\{\frac{moles\ Oxygen}{moles\ fuel}\right\}$$

So need to balance the stoichiometric relationship, this is the generalized hydrocarbon combustion relation,

$$C_mH_xO_y + zO_2 \rightarrow mCO_2 + \frac{x}{2}\,H_2O$$

Now though which you can calculate this one,

Z = m + x/4 – y/2

$$Z = \left\{\frac{moles\ Oxygen}{moles\ fuel}\right\}$$

So through which you can calculate easily calculate the minimum oxygen concentration.

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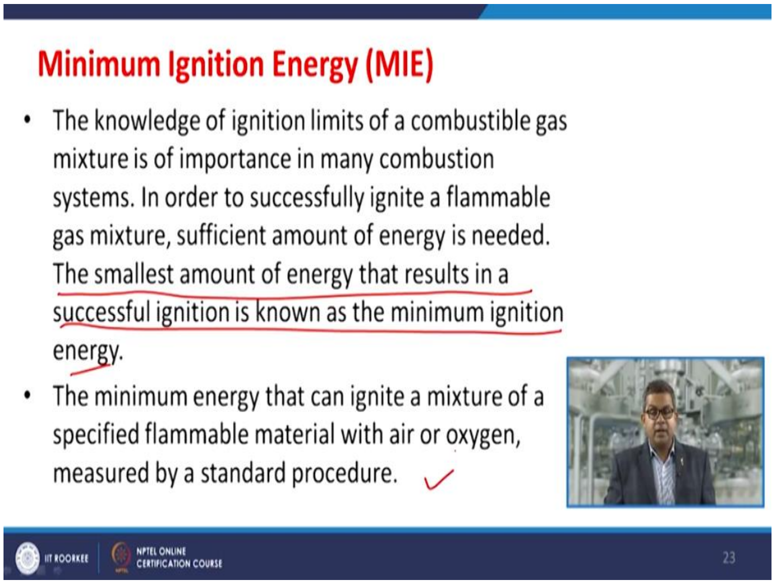

## Minimum Ignition Energy (MIE)

- The knowledge of ignition limits of a combustible gas mixture is of importance in many combustion systems. In order to successfully ignite a flammable gas mixture, sufficient amount of energy is needed. The smallest amount of energy that results in a successful ignition is known as the minimum ignition energy.
- The minimum energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure. ✓

Now we have talked about the essential requirement for a combustible mixture. Now let us have a look about the minimum ignition energy, the knowledge of ignition limits of a combustible gas mixture is of importance in many combustion system. Now in order to successfully ignite a flammable gas mixture, sufficient amount of energy is needed; the smallest amount of energy that results in the successful ignition is known as the minimum ignition energy. Now this is the standard definition, without this minimum amount of energy you cannot ignite the mixture.

So this is the minimum amount of energy required to ignite a particular mixture, now in other words a minimum energy that can ignite a mixture of specified flammable material with air or oxygen measured by a standard procedure, now this is the scientific definition of MIE.

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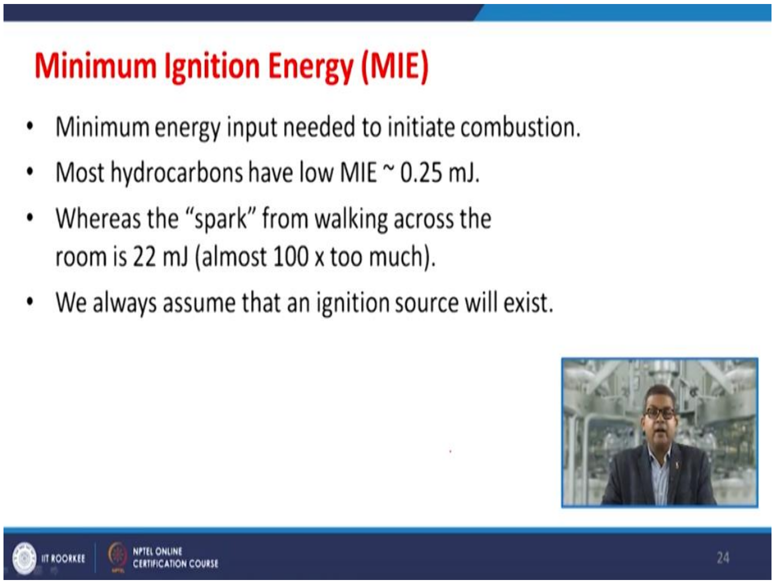

## Minimum Ignition Energy (MIE)

- Minimum energy input needed to initiate combustion.
- Most hydrocarbons have low MIE ~ 0.25 mJ.
- Whereas the "spark" from walking across the room is 22 mJ (almost 100 x too much).
- We always assume that an ignition source will exist.

Now the minimum energy input in single line aspect, you can always say that minimum energy input needed to initiate the combustion. Most hydrocarbon, they are having very low minimum ignition energy, that is around 0.25 millijoule whereas a spark from walking across the room is around 22 millijoule, so almost hundred times greater than as required for this one. That is why whenever you visit the refinery or any hydrocarbon plant it is always advisable not to use the shoes which are having the shoe nails or iron nails. So we always assume that an ignition source will exist, only thing is that we need to minimize the impact of the source of ignition.

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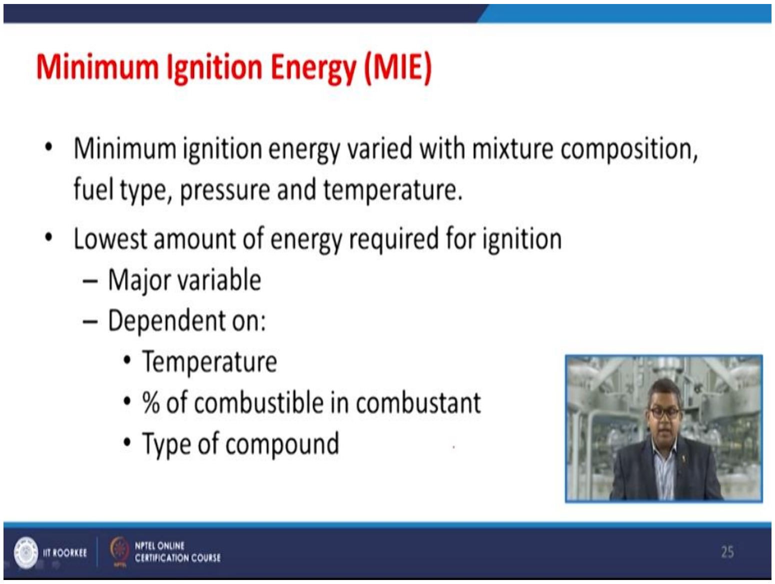

## Minimum Ignition Energy (MIE)

- Minimum ignition energy varied with mixture composition, fuel type, pressure and temperature.
- Lowest amount of energy required for ignition
  - Major variable
  - Dependent on:
    - Temperature
    - % of combustible in combustant
    - Type of compound

Now minimum ignition energy requirement varied with the mixture composition, fuel type, pressure and a temperature, so the lowest amount of energy required for the ignition depend on the major variables, those are dependent on temperature, percentage of combustible and the different type of compound which are in question because the hydrocarbon those who are having the lower molecule weight, it can easily catch the fire.

Now next is the adiabatic compression and this is most common phenomenon in hydrocarbon combustion and especially you can easily visualize this particular phenomenon when you are using your motor car and scooter which is having too high temperature or if you run across a 500-600 kilometers without giving any rest then the temperature will rise up.

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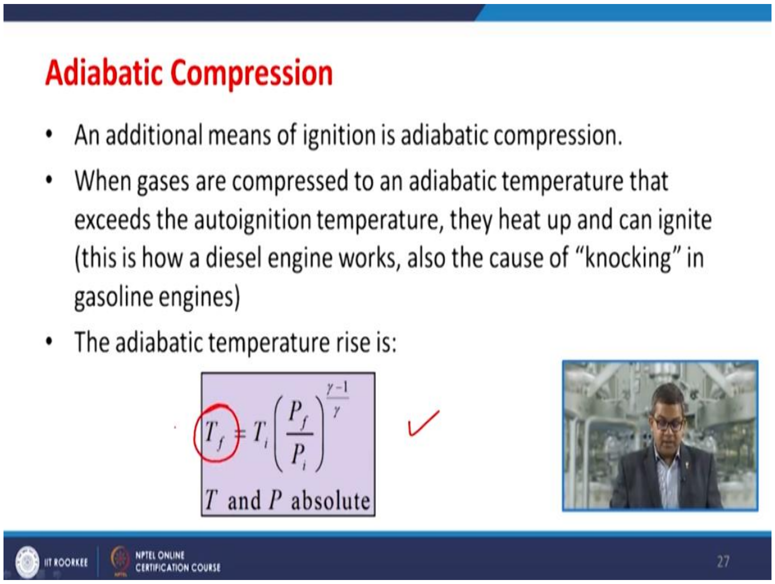

## Adiabatic Compression

- An additional means of ignition is adiabatic compression.
- When gases are compressed to an adiabatic temperature that exceeds the autoignition temperature, they heat up and can ignite (this is how a diesel engine works, also the cause of "knocking" in gasoline engines)
- The adiabatic temperature rise is:

$$T_f = T_i\left(\frac{P_f}{P_i}\right)^{\frac{\gamma-1}{\gamma}}$$ ✓

*T* and *P* absolute

So this is an additional means of ignition is the adiabatic compression. So when gases are compressed to an adiabatic temperature that exceeds the auto-ignition temperature, they heat up and can ignite. This how the diesel engine works, also the cause of knocking in various gasoline engine. So, you can calculate the adiabatic temperature by this standard thermodynamic relationship

$$T_f = T_i\left[\frac{P_f}{P_i}\right]^{\frac{\gamma-1}{\gamma}}$$

So you can calculate and if this temperature is just above your auto-ignition temperature then definitely you need to take certain attempts to minimize the effect of auto-ignition.

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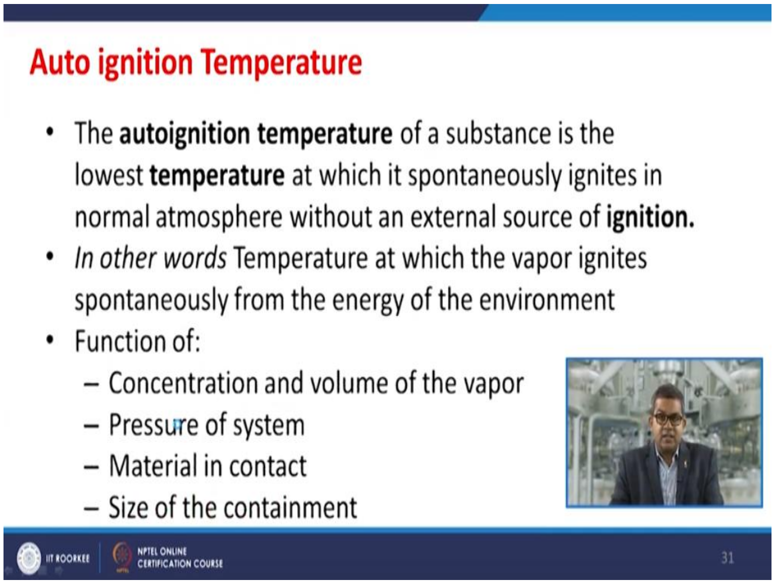

## Auto ignition Temperature

- The **autoignition temperature** of a substance is the lowest **temperature** at which it spontaneously ignites in normal atmosphere without an external source of **ignition.**
- *In other words* Temperature at which the vapor ignites spontaneously from the energy of the environment
- Function of:
  - Concentration and volume of the vapor
  - Pressure of system
  - Material in contact
  - Size of the containment

Now auto-ignition temperature because we have discussed this auto-ignition temperature in adiabatic compression then again it is a prime duty to have a look at what is auto-ignition temperature. So the auto-ignition temperature of a substance is the lowest temperature at which it is spontaneously ignite in normal atmosphere without an external source of ignition. So in other words the temperature at which the vapor ignite spontaneously from the energy of the environment. Now see if you compare with the adiabatic compression then the temperature at this paraphernalia is on the higher side.

Then auto-ignition temperature and if sufficient quantity of oxygen is available then definitely it will ignite. Now this AIT is the function of concentration and the volume of the vapor, the pressure of the system, the material in contact and size of containment. Now we have discussed various aspects of flammability characteristics and without the source of ignition you cannot imagine the fire whether it is in the positive sense or in a negative sense.

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## Ignition Sources

- An **ignition source** is a process or event which can cause a fire or explosion. Open flames, sparks, static electricity, and hot surfaces are all possible **ignition sources**.
- An explosion can occur when flammable gases or vapors in the air come in contact with an **ignition source.**
- Ignition sources are free!!!

So what is ignition source? An ignition source is a process or event which can cause a fire or explosion. Open flames, spark, static electricity and hot surfaces are all possible ignition sources, an explosion can occur when flammable gases or vapors in the air come in contact with the ignition source and remember one thing that ignition sources are almost free and available everywhere.

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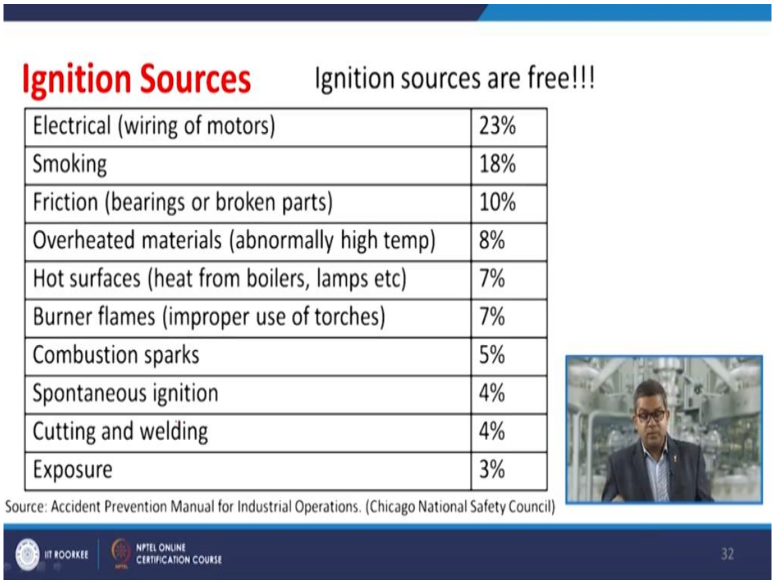

## Ignition Sources

Ignition sources are free!!!

| | |
|---|---|
| Electrical (wiring of motors) | 23% |
| Smoking | 18% |
| Friction (bearings or broken parts) | 10% |
| Overheated materials (abnormally high temp) | 8% |
| Hot surfaces (heat from boilers, lamps etc) | 7% |
| Burner flames (improper use of torches) | 7% |
| Combustion sparks | 5% |
| Spontaneous ignition | 4% |
| Cutting and welding | 4% |
| Exposure | 3% |

Source: Accident Prevention Manual for Industrial Operations. (Chicago National Safety Council)

We have collected some statistical information about the ignition sources, this is based on the accidental investigation, so electrical motor or wiring of motor they causes almost 23 percent of accident; smocking 18 percent; friction bearing or broken parts, almost 10 percent; overheated material abnormally at high temperature, almost 8 percent; hot surfaces, burner flames, combustion sparks, spontaneous ignition, cutting, welding etc.

So they all contributes, the basic purpose of this particular table is that you must know that what is the impetus of different variables through which, and what is the gravity of those variable or sources of ignition those who are incorporating in terms of accident. So we must aware that this can be a very dangerous.

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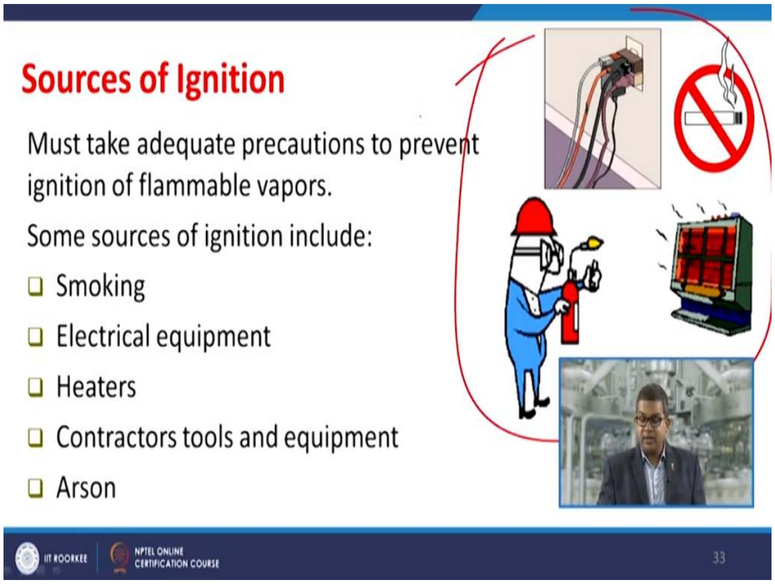

## Sources of Ignition

Must take adequate precautions to prevent ignition of flammable vapors.

Some sources of ignition include:

- ❑ Smoking
- ❑ Electrical equipment
- ❑ Heaters
- ❑ Contractors tools and equipment
- ❑ Arson

Now these sources of ignition must take adequate precaution to prevent the ignition of flammable vapors, they are some of the casual sources of ignitions are smocking, electrical equipment, so that is why if you go to refinery you are not allowed to smoke inside the refinery. The heaters, the contractor tools and equipments, arsons etc, so you can see in these pictorial figures, that there are so many sources and sometimes all these equipment may get heated or so the heat is sufficient enough to produce the spark.

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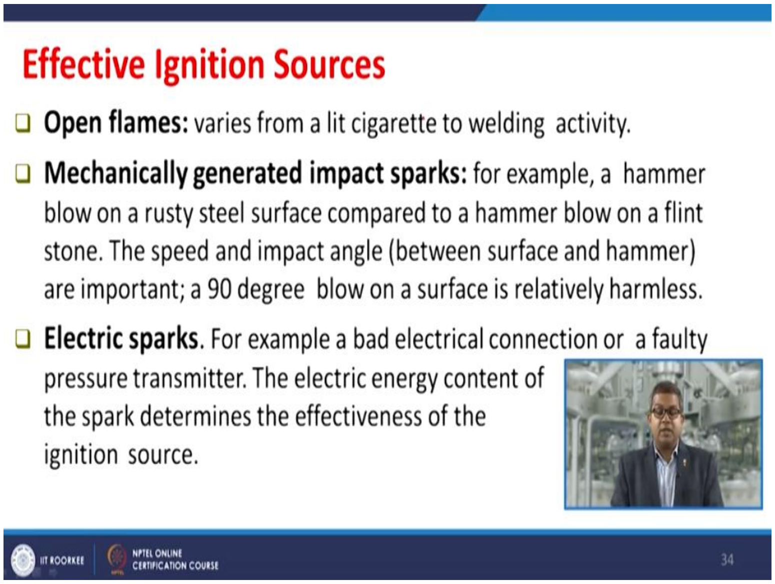

### Effective Ignition Sources

- ❑ **Open flames:** varies from a lit cigarette to welding activity.
- ❑ **Mechanically generated impact sparks:** for example, a hammer blow on a rusty steel surface compared to a hammer blow on a flint stone. The speed and impact angle (between surface and hammer) are important; a 90 degree blow on a surface is relatively harmless.
- ❑ **Electric sparks.** For example a bad electrical connection or a faulty pressure transmitter. The electric energy content of the spark determines the effectiveness of the ignition source.

There are certain open flames, they varies from to lit a cigarette to welding activity. Mechanically generated, now why I am talking about the welding activity? Sometimes, if you are working in the combustible environment and if any because of variety of reasons wear and tear may take place in any equipment and you need to perform the welding activity, so when you need to perform this welding activity you must ensure that either your workplace is cordon off or you must insure that there would be no chance of any combustible mixture within the periphery.

Now another is the mechanically generated impact spark, the few example is that hammering or hammer blow on rusty steel surface compared to the hammer blow on a flint stone, so spark may be generated. The speed and impact angle between the surface and hammer are important and 90 degree blow on the surface is relatively harmless, so you must know that at what point of time you must impact all those hammers to the surface required. Electrical spark, for example, a bad electrical connection or a faulty pressure transmitter, the electric energy content of the spark determines the effectiveness of the ignition sources.

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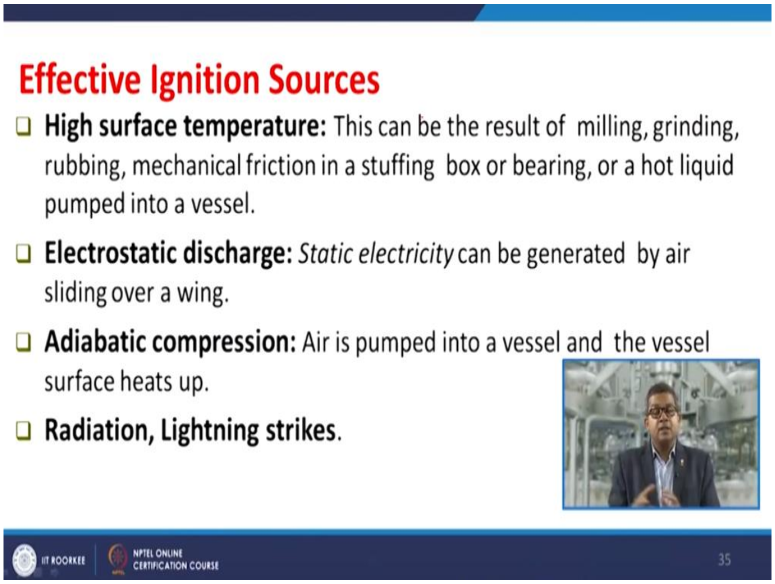

## Effective Ignition Sources

- **High surface temperature:** This can be the result of milling, grinding, rubbing, mechanical friction in a stuffing box or bearing, or a hot liquid pumped into a vessel.
- **Electrostatic discharge:** *Static electricity* can be generated by air sliding over a wing.
- **Adiabatic compression:** Air is pumped into a vessel and the vessel surface heats up.
- **Radiation, Lightning strikes**.

There sometimes you may encounter the high surface temperature, this can be the result of milling, grinding, rubbing, mechanical friction in a stuffing box or a bearing or a hot liquid pumped into a vessel. There may be enough sources. Then electrostatic discharge, static discharge can be generated by the air sliding over a wing or even the pipeline transfer of any hydrocarbon from one place to another place. Then adiabatic compression, sometimes air is pumped into vessel and the vessel surface heats up, then again it may cause the adiabatic compression. Radiation, lighting etc, because in history there are so many accidents they are attributed to this type of ignition sources.

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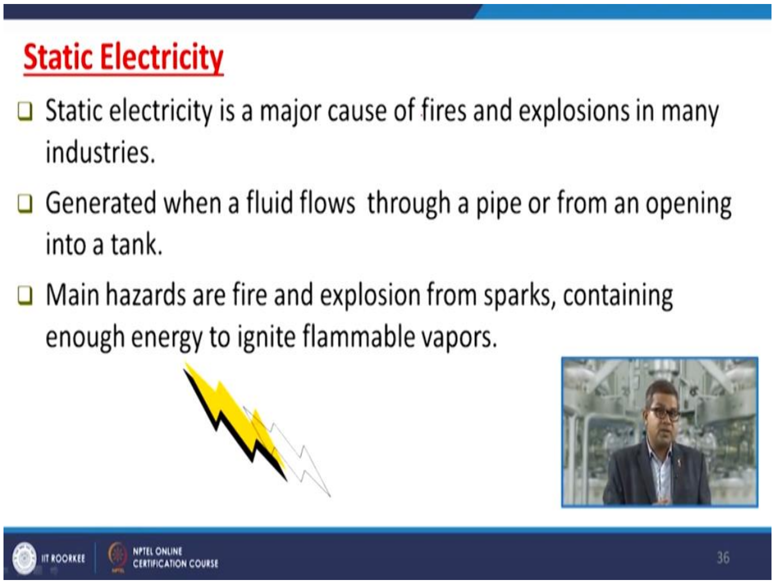

## Static Electricity

- ❑ Static electricity is a major cause of fires and explosions in many industries.
- ❑ Generated when a fluid flows through a pipe or from an opening into a tank.
- ❑ Main hazards are fire and explosion from sparks, containing enough energy to ignite flammable vapors.

Then there is chance of static electricity, it is major cause of fire and explosion in many industries, and generated when fluid flows through a pipe or from an opening into a tank. Main hazard are fire and explosion from spark containing enough energy to ignite the flammable vapors, so we must know and there is any chance of generation of static electricity, the system must be properly grounded, bounded etc, we will discuss in subsequent modules.

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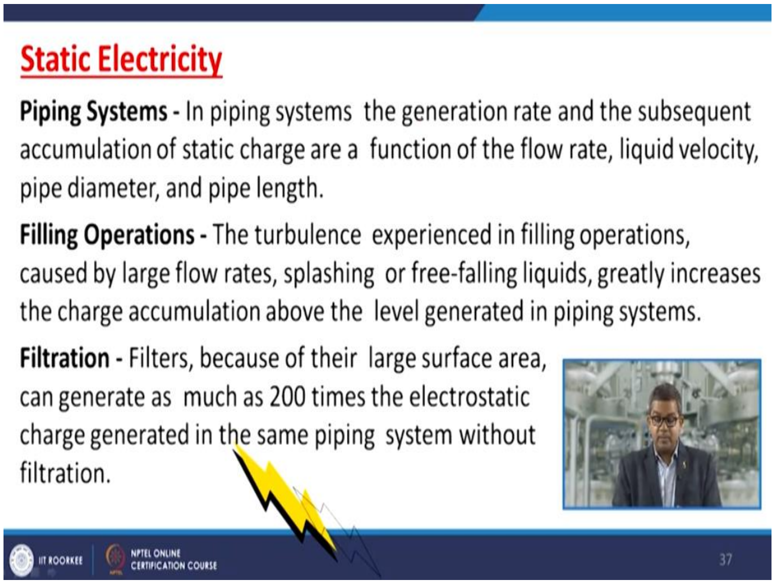

## Static Electricity

**Piping Systems -** In piping systems the generation rate and the subsequent accumulation of static charge are a function of the flow rate, liquid velocity, pipe diameter, and pipe length.

**Filling Operations -** The turbulence experienced in filling operations, caused by large flow rates, splashing or free-falling liquids, greatly increases the charge accumulation above the level generated in piping systems.

**Filtration -** Filters, because of their large surface area, can generate as much as 200 times the electrostatic charge generated in the same piping system without filtration.

They are so many piping systems; they are responsible for generation of electricity, static electricity. So in piping system the generation rate and the subsequent accumulation of static charges are function of flow rate, liquid velocity, pipe diameter and a pipe length. So as a chemical engineer you must know that what kind of parameter those who are impacting the generation of static electricity in the piping system. Then filling operation, the turbulence experienced in the filling operation usually caused by large flow rate, splashing.

Free falling liquids greatly increase the charge accumulation above the liquid generated in the piping system, we will discuss this filling operation in subsequent modules. Filtration, filter because of their large surface area can generate as much as 200 times the electrostatic charge generated in the piping system without filtration.

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## Auto-Oxidation

- The process of slow oxidation with accompanying evolution of heat, sometimes leading to auto ignition if the energy is not removed from the system.
- Liquids with relatively low volatility are particularly susceptible to this problem.
- *Liquids with high volatility are less susceptible to auto ignition because they self-cool as a result of evaporation.*
- Known as **spontaneous combustion** when a fire results; e.g., oils on a rag in a warm storage area, insulation on a steam pipe saturated with certain polymers.

An another important aspect is the auto oxidation, the process of slow oxidation accompanying evolution of heat sometimes leading to auto-ignition if energy is not removed from the system. Liquid with relatively low volatile are particularly susceptible to this problem and liquid with the high volatility are less susceptible to auto-ignition because they self-cool as a result of evaporation. So this is sometimes known as spontaneous combustion when the fire results in oil on a rags in a warm storage area. Sometimes it is quite common when you store the oil bearing seeds in the closed silos and sometimes because of this auto-ignition ability you may experience the rise in temperature.

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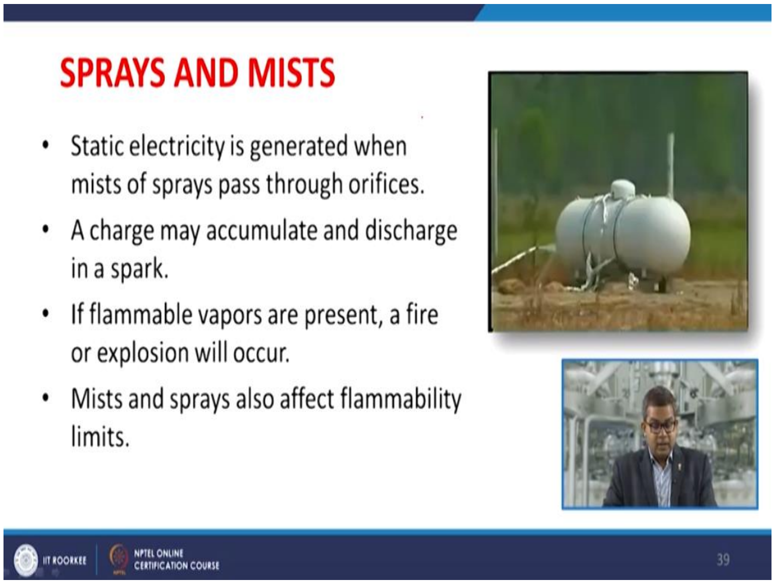

SPRAYS AND MISTS

- Static electricity is generated when mists of sprays pass through orifices.
- A charge may accumulate and discharge in a spark.
- If flammable vapors are present, a fire or explosion will occur.
- Mists and sprays also affect flammability limits.

Then sometimes spray and mist, they do contribute towards the generation of static charges, so static electricity is generated when mists of spray is passed through an orifice, a charge may accumulate and discharge in a spark. If flammable vapors are present, a fire or explosion will occur. And mist and sprays also affect the flammability limits, so do care because sometimes if you are spraying the inert material to a particular zone then definitely you cannot overlook the importance of generation of spray and mist.

So in this particular module we have discussed about the various flammability characteristics, various aspects, we have gone through the different type of parameters and especially LFL and UFL because these particular aspects are essential and important while designing the safety or devices in a particular workplace. Thank you very much.