Plant Design and Economics

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Lecture No -53

Fires And Explosions: Prevention

Welcome to lecture 53, of Plant Design and Economics. In this module we are talking about chemical process safety. In our previous lecture, we have talked about flammability characteristics of fire and explosions. So we will continue our discussion on fires and explosions and in this lecture we will also look at, the prevention of fires and explosions.

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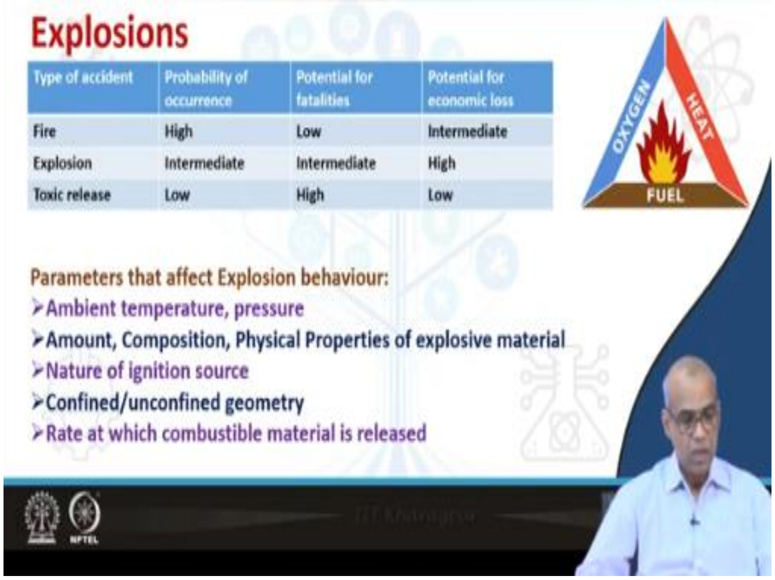

Explosions

Type of accident	Probability of occurrence	Potential for fatalities	Potential for economic loss
Fire	High	Low	Intermediate
Explosion	Intermediate	Intermediate	High
Toxic release	Low	High	Low

Parameters that affect Explosion behaviour:

- ➢Ambient temperature, pressure
- ➢Amount, Composition, Physical Properties of explosive material
- ➢Nature of ignition source
- ➢Confined/unconfined geometry
- ➢Rate at which combustible material is released

Explosion is essentially, rapid release of energy. There are several parameters that affect the behaviour of an explosion. For example, Ambient Temperature, Ambient Pressure, Amount of explosive material, Composition of explosive material, physical properties of explosive material, Nature of ignition source. Whether the explosion is taking place in a confined geometry or in an open space. Also, at which at the rate at which the; combustible material is released. So, there are multiple parameters that will affect the explosion behaviour.

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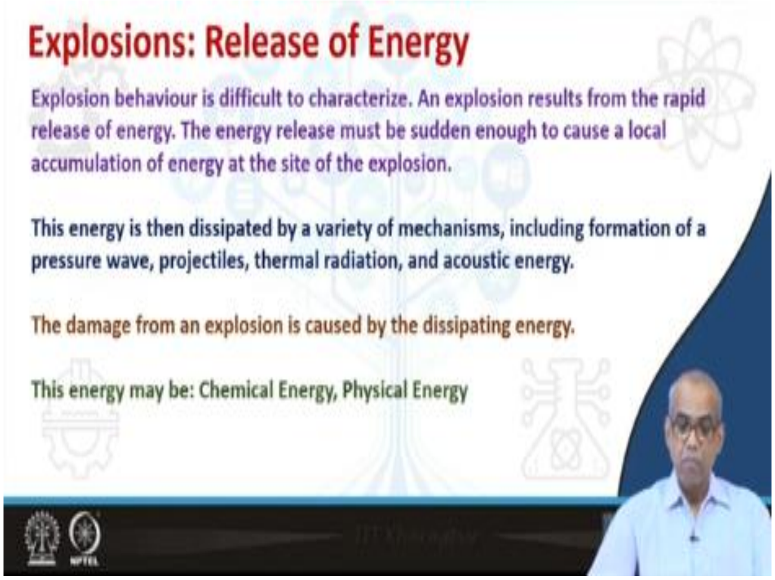

Explosions: Release of Energy

Explosion behaviour is difficult to characterize. An explosion results from the rapid release of energy. The energy release must be sudden enough to cause a local accumulation of energy at the site of the explosion.

This energy is then dissipated by a variety of mechanisms, including formation of a pressure wave, projectiles, thermal radiation, and acoustic energy.

The damage from an explosion is caused by the dissipating energy.

This energy may be: Chemical Energy, Physical Energy

And that is one of the reason why explosion behaviour is so difficult to characterize. An explosion results from the rapid release of energy. The energy release must be sudden. And it must be sudden enough to cause a local accumulation of energy at the site, where explosion is taking place. So, the explosion is characterized by energy release and also, this energy release must be certain enough to cause a local accumulation of energy at the site of explosion.

Then, this accumulated energy will be dissipated by several mechanisms. For example, the accumulated energy may be dissipated as pressure waves, as acoustic energy thermal radiation, etcetera. The damage form explosion occurs, because of this dissipating energy. Such energy may be chemical energy, as well as physical energy.

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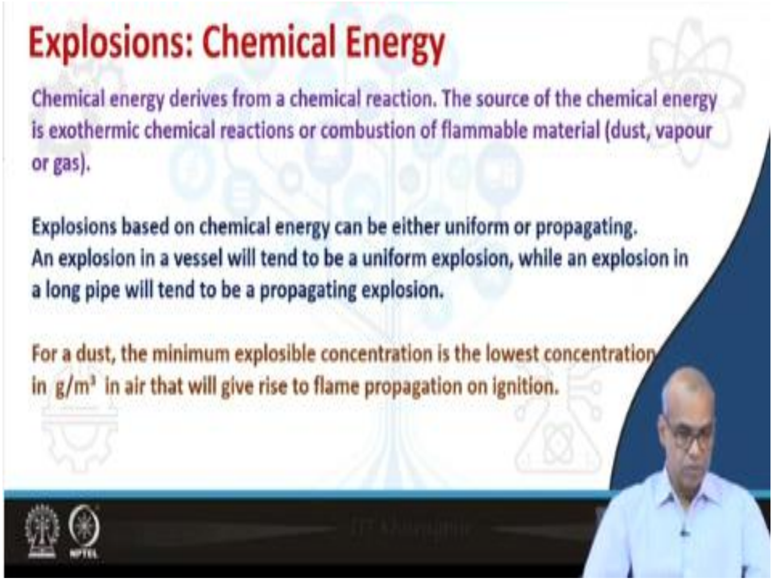

Explosions: Chemical Energy

Chemical energy derives from a chemical reaction. The source of the chemical energy is exothermic chemical reactions or combustion of flammable material (dust, vapour or gas).

Explosions based on chemical energy can be either uniform or propagating.
An explosion in a vessel will tend to be a uniform explosion, while an explosion in a long pipe will tend to be a propagating explosion.

For a dust, the minimum explosible concentration is the lowest concentration in g/m^3 in air that will give rise to flame propagation on ignition.

Chemical energy derives from a chemical reaction. The source of the chemical energy is exothermic chemical reactions or combustion of flammable material. The flammable materials may be dust, it may be vapour, or it may be gas. Explosion based on chemical energy, can be either uniform or propagating in nature. For example, consider that explosion is taking place in a long pipe.

Now, this will tend to be a propagating type explosion whereas, the explosion occurring in a vessel will tend to be a uniform explosion. When a dust is exploding, how do I express the minimum explosible concentration of the dust, which is dispersed in a gas? The minimum explosible concentration, is the lowest concentration in gram per meter cube in air, that will give rise to flame propagation once it is ignited.

So the minimum quantity of dust in gram per meter cube in air, that will give rise to flame propagation on ignition. So that is, what is explosive concentration, minimum explosive concentration for dust.

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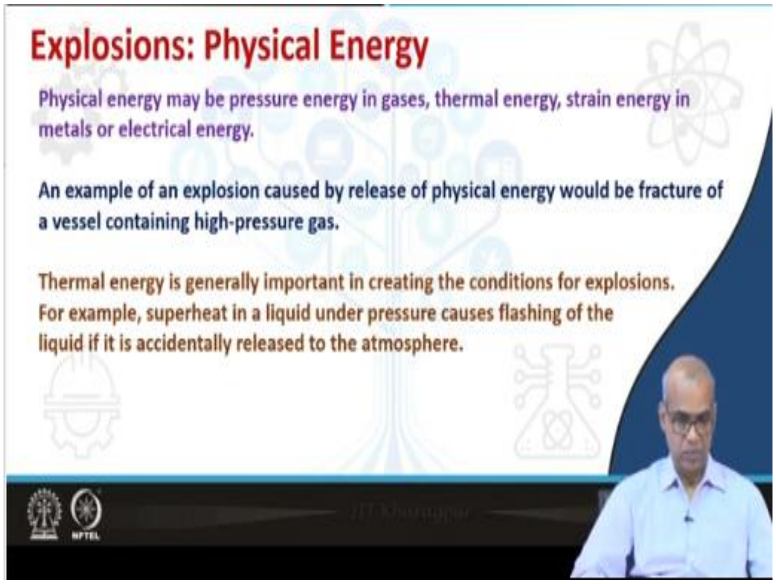

Explosions: Physical Energy

Physical energy may be pressure energy in gases, thermal energy, strain energy in metals or electrical energy.

An example of an explosion caused by release of physical energy would be fracture of a vessel containing high-pressure gas.

Thermal energy is generally important in creating the conditions for explosions. For example, superheat in a liquid under pressure causes flashing of the liquid if it is accidentally released to the atmosphere.

Now, we have seen that, chemical energies coming from explosions. How about physical energy? Physical energy may be pressure energy's gases, thermal energy, strain energy in metals or electrical energy. An example of an explosion caused by release of physical energy would be fracture of a vessel containing high pressure gas. So imagine the fracture of a vessel which contains a gas in high pressure.

So explosion of such a vessel will be caused by release of physical energy. Thermal energy is generally important in creating the conditions for the explosion. So it is, generally not the source of energy for explosion. Thermal radiation is generally, important in creating the conditions for explosion. So it creates the conditions for explosions, rather than the source of energy for the explosion.

Consider, a superheated liquid, under pressure. If, a superheated liquid under pressure, is accidentally released to the atmosphere then it will cause flashing.

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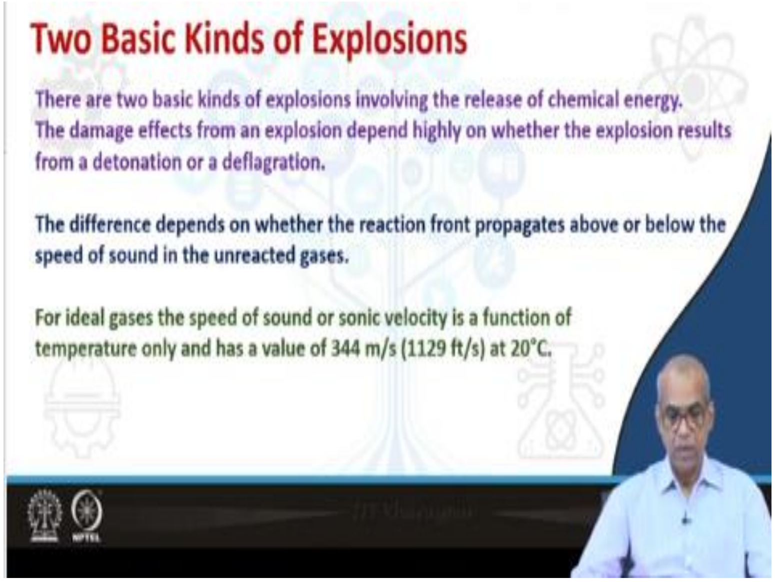

Two Basic Kinds of Explosions

There are two basic kinds of explosions involving the release of chemical energy. The damage effects from an explosion depend highly on whether the explosion results from a detonation or a deflagration.

The difference depends on whether the reaction front propagates above or below the speed of sound in the unreacted gases.

For ideal gases the speed of sound or sonic velocity is a function of temperature only and has a value of 344 m/s (1129 ft/s) at 20°C.

There are two basic kinds of explosion. They are deflagration and detonation. The two basic kinds of explosions, involve release of chemical energy. They cause damages to different extent. The damage effects from an explosion depend highly on whether the explosion results, from a detonation or deflagration. The difference, between deflagration and detonation is based on the fact that whether the reaction front propagates above the sound, speed of sound or below the speed of the sound.

So depending on whether, the reaction front propagates above the speed of the sound or below the speed of the sound in the unreacted gases, we have two basic kinds of explosions, known as deflagration and detonation. For ideal gases the speed of sound or sonic velocity, is a function of temperature only, and its value is 344 meter per second at 20 degree Celsius. So, the 2 basic kinds of explosion, deflagration or detonation are based on whether the reaction front propagates, above this velocity, this 344 meter per second at 20 degree Celsius velocity or not.

So this is the reference, but note that this 344 meter per second is the speed of the sound at the 20 degree Celsius and speed of the sound for ideal gases, is a function of temperature alone.

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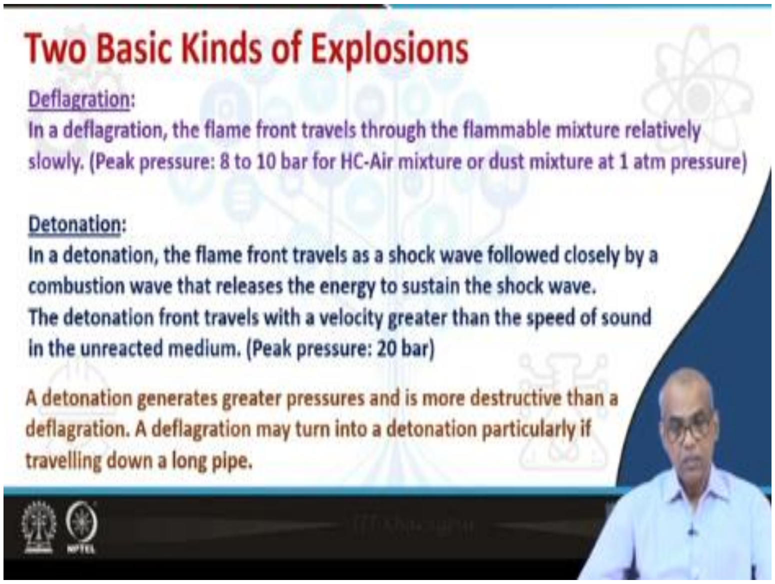

Two Basic Kinds of Explosions

Deflagration:

In a deflagration, the flame front travels through the flammable mixture relatively slowly. (Peak pressure: 8 to 10 bar for HC-Air mixture or dust mixture at 1 atm pressure)

Detonation:

In a detonation, the flame front travels as a shock wave followed closely by a combustion wave that releases the energy to sustain the shock wave.
The detonation front travels with a velocity greater than the speed of sound in the unreacted medium. (Peak pressure: 20 bar)

A detonation generates greater pressures and is more destructive than a deflagration. A deflagration may turn into a detonation particularly if travelling down a long pipe.

In a deflagration, the flame front travels through the flammable mixture relatively slowly. So here, the reaction front propagates, with a speed which is lower than the speed of the sound. It causes relatively less damage. The peak pressure, for deflagration of hydrocarbon air mixture or a dust mixture, at one atmospheric pressure is about 8 to 10 bars. Corresponding peak pressure for detonation will be much higher.

In a detonation, the flame front travels as a shock wave, followed closely by a combustion wave that releases the energy to sustain the shock wave. Here, the detonation front travels with a velocity greater than the speed of sound in the unreacted medium. And it causes much greater damage compared to deflagration. So deflagration causes less damage. Its flame front or the reaction front travels, with the speed lower than that of sound and the typical peak pressure for say hydrocarbon air mixture is about 8 to 10 bar whereas detonation, is much powerful explosion.

Here, the reaction front travels at a speed higher than that of the sound. Here, the peak pressure is about 20 bar. A detonation generates greater pressure and is more destructive than a deflagration. A deflagration may turn into a detonation, particularly if it is travelling, down along pipe. So, it is possible, that a deflagration will turn into a detonation, but this typically happens when the deflagration happens, in a long pipe.

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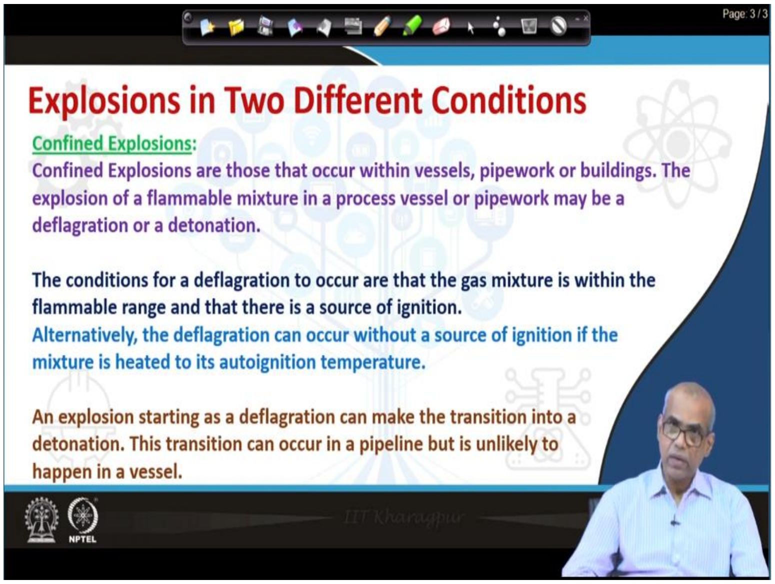

Explosions in Two Different Conditions

Confined Explosions:

Confined Explosions are those that occur within vessels, pipework or buildings. The explosion of a flammable mixture in a process vessel or pipework may be a deflagration or a detonation.

The conditions for a deflagration to occur are that the gas mixture is within the flammable range and that there is a source of ignition.

Alternatively, the deflagration can occur without a source of ignition if the mixture is heated to its autoignition temperature.

An explosion starting as a deflagration can make the transition into a detonation. This transition can occur in a pipeline but is unlikely to happen in a vessel.

The way we have two different kinds of explosion such as deflagration and detonation, we also have explosions occurring in two different conditions. These two different conditions are like whether the explosion takes place in a confined geometry will call that as confined explosion or the explosion takes place in an unconfined geometric when in open space will call that unconfined explosion.

So, confined explosions are those that occur within vessels, pipe work or building. The explosions of a flammable mixture in a process vessel or pipe work, maybe a deflagration or detonation. Note that here the distinction is based on the conditions of explosions, whether the explosion is taken place in a confined geometry or not. So the confined explosions can be both deflagration or a detonation, because the deflagration and detonation based on whether the reaction from propagates above the speed of the sound or below the speed of the sound.

The conditions for a deflagration to occur are that the gas mixture is within the flammable range and that there is a source of ignition. This is obvious that the gas mixture has to be flammable, it must not lie in the non-flammable region if a plot on that triangular diagram and of course, there will be a source of ignition. So basically if you consider the triangle or even the fire triangle you need to have a flammable fuel unit to have source of ignition as well as you need to have oxygen.

Alternatively the deflagration can occur without a source of ignition but then in that case the mixture must be heated to its auto ignition temperature, so that the cell ignition can take place. An explosion starting as a deflagration can make the transition into a detonation and as we just discussed previously that this can occur in the pipeline, but it is quite unlikely that will occur in a vessel.

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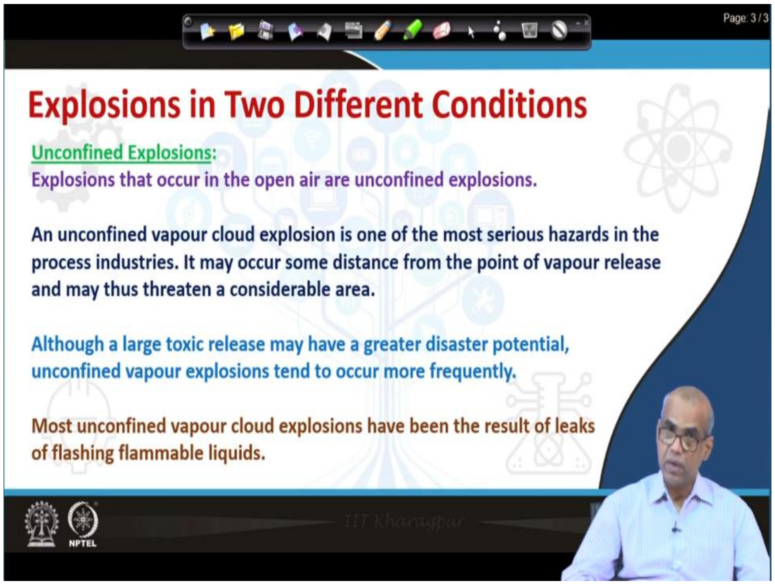

Explosions in Two Different Conditions

Unconfined Explosions:
Explosions that occur in the open air are unconfined explosions.

An unconfined vapour cloud explosion is one of the most serious hazards in the process industries. It may occur some distance from the point of vapour release and may thus threaten a considerable area.

Although a large toxic release may have a greater disaster potential, unconfined vapour explosions tend to occur more frequently.

Most unconfined vapour cloud explosions have been the result of leaks of flashing flammable liquids.

Now the other explosions or the explosions in other conditions unconfined explosions. Explosions that occur in the open air will be termed as unconfined explosions. One of the most serious unconfined explosion hazard comes when an unconfined vapour cloud explodes. So an unconfined vapour cloud explosion is one of the most serious hazard in a chemical process industry.

The problem is this that such an explosion can occur some distance away from the point of vapour release and thus it can threaten not only the core industrial area, but also a considerable region away from the point of vapour release. Although a large toxic release may have a greater disaster potential we know that the disaster potential with fire is low then with explosion it is intermediate and with toxic release it is highest.

So although a large oxygen release may have a greater disaster potential unconfined vapour explosion tend to occur more frequently than toxic release. Most unconfined vapour cloud explosions have been the result of leaks of flashing flammable liquids. So, we must take good care of leaking of flashing flammable liquids.

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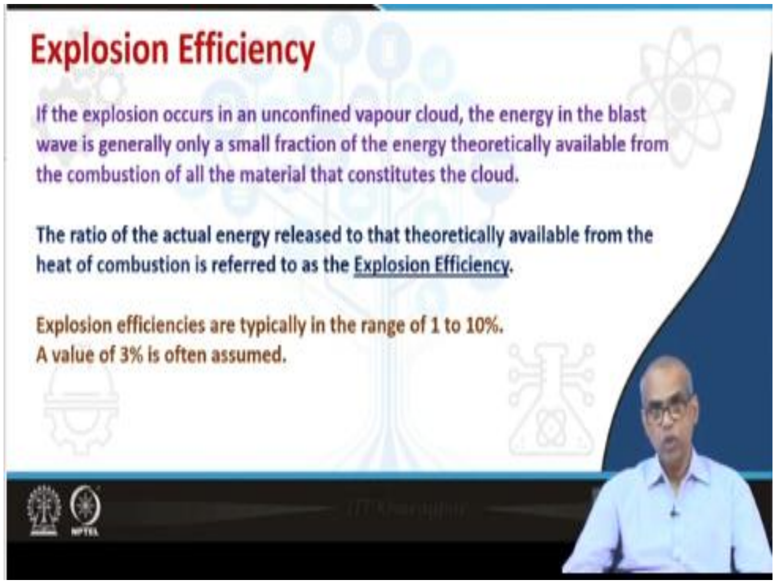

Explosion Efficiency

If the explosion occurs in an unconfined vapour cloud, the energy in the blast wave is generally only a small fraction of the energy theoretically available from the combustion of all the material that constitutes the cloud.

The ratio of the actual energy released to that theoretically available from the heat of combustion is referred to as the Explosion Efficiency.

Explosion efficiencies are typically in the range of 1 to 10%.
A value of 3% is often assumed.

Now we will define a term called explosion efficiency. If the explosion occurs in an unconfined vapour cloud the energy in the blast wave is generally only a small fraction of the energy theoretically available from the combustion of all the materials that constitute the cloud. Now the explosion efficiency is defined as the ratio of the actual energy released to that theoretical available from the heat of combustion.

So the ratio of the actual energy released to that theoretically available from the heat of combustion is called explosion efficiency. The typical values of the explosion efficiency lie in the range of 1% to 10%, frequently a value of 3% is often assumed.

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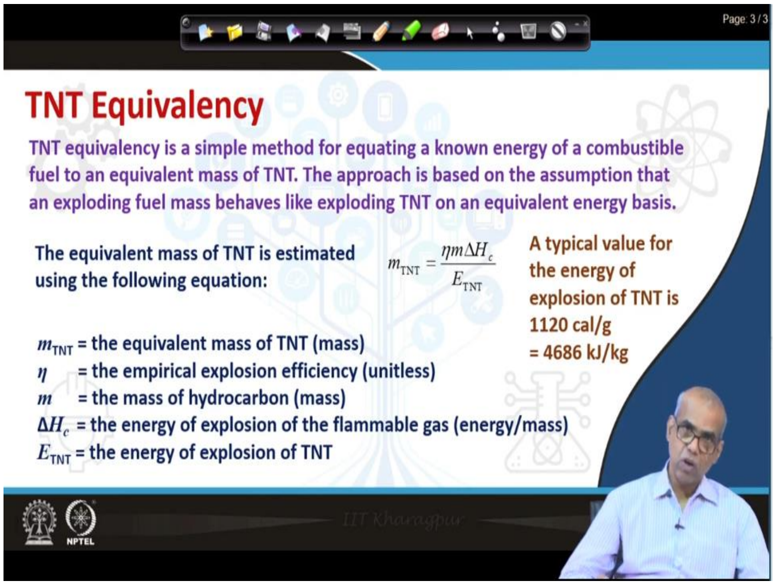

TNT Equivalency

TNT equivalency is a simple method for equating a known energy of a combustible fuel to an equivalent mass of TNT. The approach is based on the assumption that an exploding fuel mass behaves like exploding TNT on an equivalent energy basis.

The equivalent mass of TNT is estimated using the following equation:

$$m_{\mathrm{TNT}} = \frac{\eta m \Delta H_c}{E_{\mathrm{TNT}}}$$

A typical value for the energy of explosion of TNT is 1120 cal/g = 4686 kJ/kg

m_{TNT} = the equivalent mass of TNT (mass)
η = the empirical explosion efficiency (unitless)
m = the mass of hydrocarbon (mass)
ΔH_c = the energy of explosion of the flammable gas (energy/mass)
E_{TNT} = the energy of explosion of TNT

TNT equivalency is a term that is frequently used to make a comparison between the explosion effect of an explosive material of a given explosive material with the explosion effect of well known explosive TNT. TNT equivalency is a simple method for equating unknown energy of a combustible fuel to an equivalent mass of TNT. The approach is based on the assumption that an exploding fuel mass behaves like exploding TNT on an equivalent energy basis.

So the equivalent mass of TNT is estimated using this equation which is explosion efficiency multiplied by the mass of fuel let us say hydrocarbon, multiplied by delta H c which is energy of explosion of the flammable gas, divided by the energy of explosion of TNT. So this equation can be used to find out the TNT equivalency or equivalent mass of TNT, equivalent in what sense equivalent in the release of energy on explosion.

A typical value of energy of explosion of TNT that is E TNT is 1,120 calorie per gram. So TNT equivalency can be computed using the formula given and this is often used to compare the explosion effect by comparing with the explosion of TNT.

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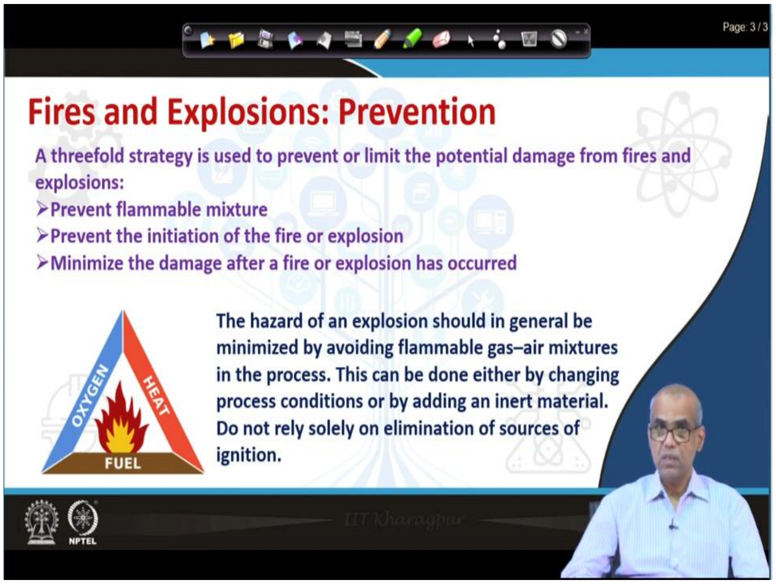

Fires and Explosions: Prevention

A threefold strategy is used to prevent or limit the potential damage from fires and explosions:

- ➢Prevent flammable mixture
- ➢Prevent the initiation of the fire or explosion
- ➢Minimize the damage after a fire or explosion has occurred

The hazard of an explosion should in general be minimized by avoiding flammable gas–air mixtures in the process. This can be done either by changing process conditions or by adding an inert material. Do not rely solely on elimination of sources of ignition.

Now let us look at few steps for prevention of fires and explosions. A threefold strategy is used to prevent or limit the potential damage from fires and explosion. Those are prevent flammable mixture, prevent the initiation of the fire or explosion and minimize the damage after a fire or explosion has occurred. The hazard of an explosion should in general be minimized by avoiding flammable gas air mixtures in the process.

So if we can avoid the flammable gas air mixtures in the process the hazard of an explosion will be greatly minimized and how do I avoid flammable gas air mixtures in the process? We can do that either by changing the process conditions or by adding an inert material. Such as carbon dioxide, nitrogen, etcetera. We should not realize solely on the elimination of sources of ignition, because we have seen in previous lectures there is a long list of sources of ignition and it is very difficult to ensure that elimination of all sources of energy ignition has taken place.

So it is not a very good idea to realize solely on elimination of sources of ignition, we should try to eliminate the sources of ignition, but let us not depend only on that because it may not be possible to eliminate all possible sources of ignition.

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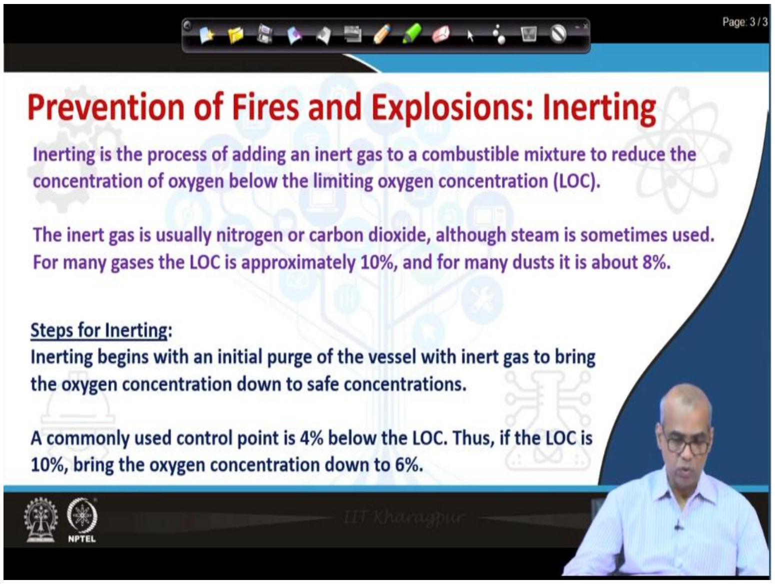

Prevention of Fires and Explosions: Inerting

Inerting is the process of adding an inert gas to a combustible mixture to reduce the concentration of oxygen below the limiting oxygen concentration (LOC).

The inert gas is usually nitrogen or carbon dioxide, although steam is sometimes used. For many gases the LOC is approximately 10%, and for many dusts it is about 8%.

Steps for Inerting:
Inerting begins with an initial purge of the vessel with inert gas to bring the oxygen concentration down to safe concentrations.

A commonly used control point is 4% below the LOC. Thus, if the LOC is 10%, bring the oxygen concentration down to 6%.

Inerting is an important way, is an important means or strategy for prevention of fires and explosion. Inerting is the process of adding an inert gas to a combustible mixture to reduce the concentration of oxygen below the limiting oxygen concentration. So, if the gas mixture is taken to the condition where the oxygen concentration is below limiting oxygen concentration, we know that it will not explode, fires an explosion will not occur. The inert gas is usually nitrogen or carbon dioxide although sometimes steam is also used.

For many cases the limiting oxygen concentration is approximately 10% and for many dusts it is about 8%. So a value of 10% is a good number. So what are the steps for inerting? Inerting begins with an initial part of the vessel with inert gas such as nitrogen carbon dioxide and sometimes steam to bring the oxygen concentration down to safe concentration. What is the safe concentration? Below the limiting oxygen concentration.

Typically we go 4% below the limiting oxygen concentration, so if the limiting oxygen concentration is 10% typically, that is the value for several gases we must bring down the oxygen concentration down to 6%. So 4% below the limiting oxygen concentration. So, there is a typical rule that is to be followed or guidelines to be followed.

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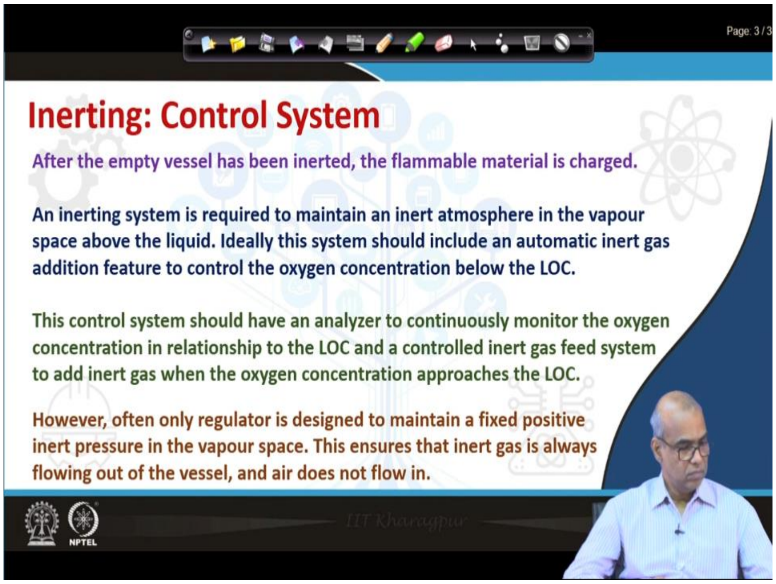

Inerting: Control System

After the empty vessel has been inerted, the flammable material is charged.

An inerting system is required to maintain an inert atmosphere in the vapour space above the liquid. Ideally this system should include an automatic inert gas addition feature to control the oxygen concentration below the LOC.

This control system should have an analyzer to continuously monitor the oxygen concentration in relationship to the LOC and a controlled inert gas feed system to add inert gas when the oxygen concentration approaches the LOC.

However, often only regulator is designed to maintain a fixed positive inert pressure in the vapour space. This ensures that inert gas is always flowing out of the vessel, and air does not flow in.

After the empty vessel has been inerted, the flammable material is charged. An inerting system is required to maintain an inert atmosphere in the vapour space above the liquid. So above the liquid in the vapour space, an inerting system is required to maintain an inert atmosphere. So basically there should be an automatic control system in place to do this job. So ideally this system should include an automatic inert gas addition to control the oxygen concentration below the LOC that is limiting oxygen concentration.

What will this control system do? This control system will continuously monitor the oxygen concentration. How will it do that? So it needs a sensor and analyzer. So it will continuously sense or analyze the oxygen concentration in the vapour space above the liquid and monitor the limiting oxygen concentration. So if there is any deviation from the limiting oxygen concentration, a control inert gas fit system will be activated to add inert gas.

So, that the oxygen concentration approaches the limiting oxygen concentration. However such elaborate system is not followed always, that means an analyzer that means the sensor along with the automatic control system is not always placed whether we should do that, but what is often done is only a regulator is designed to maintain a fixed positive inert pressure in the vapour space.

Your family will the regulator we have seen regulator in our domestic LPG cylinder used for cooking. So a regulator is designed to maintain a fixed positive inner pressure in the vapour space. What does regulator will do is the regulator will ensure that inert gas is always flowing out of the vessel and no air flows inside the vessel. So thereby it will ensure safety.

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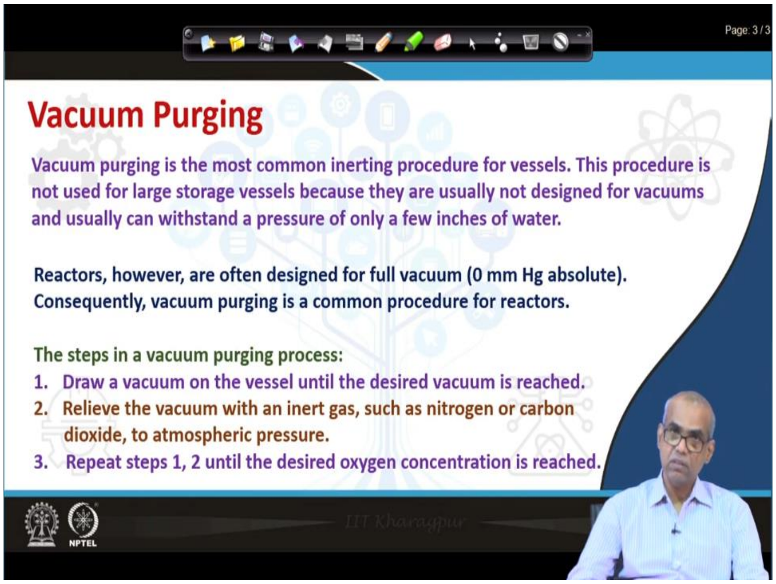

Vacuum Purging

Vacuum purging is the most common inerting procedure for vessels. This procedure is not used for large storage vessels because they are usually not designed for vacuums and usually can withstand a pressure of only a few inches of water.

Reactors, however, are often designed for full vacuum (0 mm Hg absolute). Consequently, vacuum purging is a common procedure for reactors.

The steps in a vacuum purging process:

1. Draw a vacuum on the vessel until the desired vacuum is reached.
2. Relieve the vacuum with an inert gas, such as nitrogen or carbon dioxide, to atmospheric pressure.
3. Repeat steps 1, 2 until the desired oxygen concentration is reached.

Vaccum purging is the most common inerting procedure for vessels this procedure is not used for large storage vessels because they are usually not designed for vacuums and usually can withstand a pressure of only few inches of water. However, reactors are often designed for full vacuum that means zero millimeter a mercury absolute. Therefore the vacuum purging is common procedure for reactors. The steps in a vacuum purging process are as follows.

Draw a vacuum on the vessel until the desired vacuum is reached. Relieve the vacuum with an inert gas such as nitrogen or carbon dioxide to atmospheric pressure and repeat these two steps until the desired oxygen concentration is reached.

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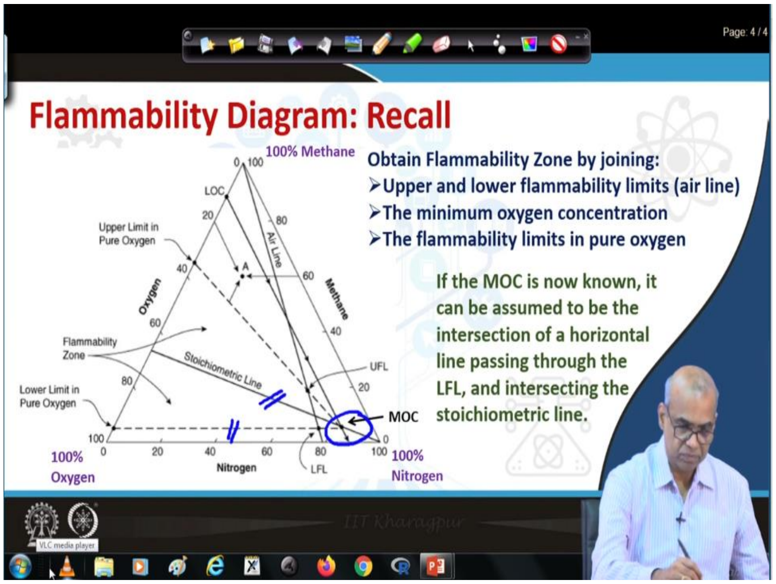

Flammability Diagram: Recall

Obtain Flammability Zone by joining:

- Upper and lower flammability limits (air line)
- The minimum oxygen concentration
- The flammability limits in pure oxygen

If the MOC is now known, it can be assumed to be the intersection of a horizontal line passing through the LFL, and intersecting the stoichiometric line.

Now, let us recall the flammability diagram that we discussed previously we can make use of this flammability diagram to ensure safety. We discuss that the flammability diagram can be obtained by joining the lower flammability limit. The lower limits in pure oxygen and the minimum oxygen concentration or limiting oxygen concentration and also by joining the minimum oxygen concentration upper flammability limit and the upper limit in pure oxygen.

And then we have this airline as well as the stoichiometric line, but this region that we obtained by joining the UFL, LFL as well as minimum oxygen concentration pure limit, lower limit in pure oxygen and upper limit in pure oxygen this region is known as flammability zone. So any mixture that lies within zone will be flammable any mixture routers outside this zone will not be flammable. So to ensure that we are not within the flammable region we can take help of such flammability diagram.

Note that in case this minimum oxygen concentration is not known it can be assumed to be the intersection of a horizontal line passing through LFL and intersecting the stoichiometric line. So that is an approximation, but that approximation can be done.

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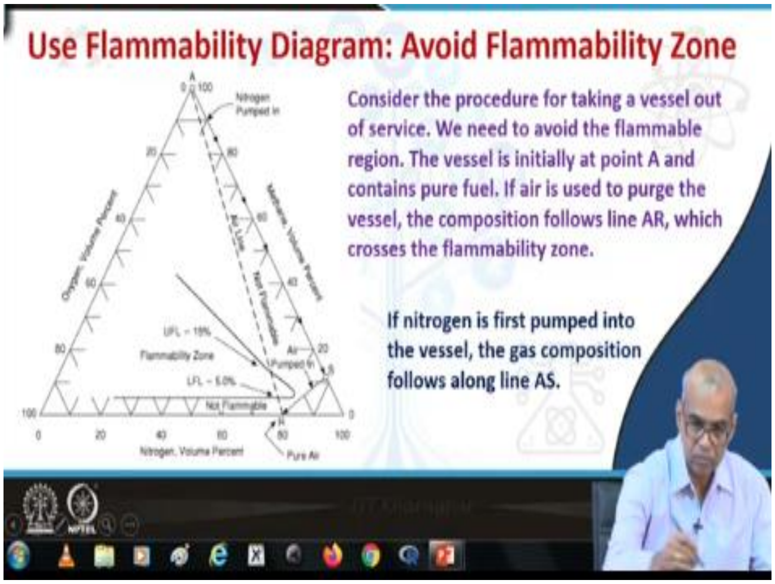

Use Flammability Diagram: Avoid Flammability Zone

Consider the procedure for taking a vessel out of service. We need to avoid the flammable region. The vessel is initially at point A and contains pure fuel. If air is used to purge the vessel, the composition follows line AR, which crosses the flammability zone.

If nitrogen is first pumped into the vessel, the gas composition follows along line AS.

So how do I use a flammability diagram to avoid flammability zone? Let us consider for example the case where we are taking a vessel out of service. So the vessel is initially at point A which corresponds to 100% fuel that means it contains pure fuel. Now if air is used to purge if I use air to purge the vessel the composition will follow the air line and ultimately when the vessel completely filled with pure air, I will have point R which represents pure air and that is a nitrogen oxygen mixture.

This is pure nitrogen apex and this is pure oxygen, 79 % nitrogen and 21% oxygen, but the problem is we cross the flammability zone, so there is danger. On the other hand if nitrogen is first pumped into the vessel, then we are obtaining nitrogen fuel mixture. So we will pass through this side, so the mixtures will be represented by points on this line, this side of the triangle because this represents a binary mixture of nitrogen and methane or fuel.

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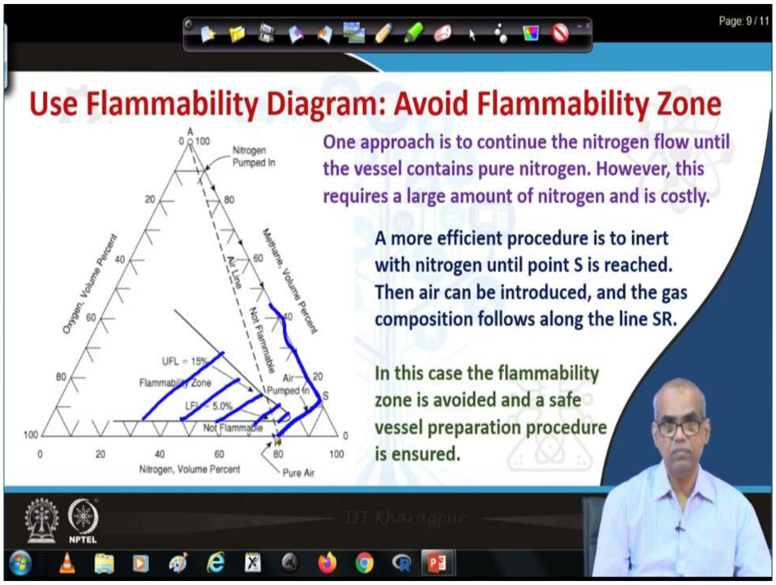

Use Flammability Diagram: Avoid Flammability Zone

One approach is to continue the nitrogen flow until the vessel contains pure nitrogen. However, this requires a large amount of nitrogen and is costly.

A more efficient procedure is to inert with nitrogen until point S is reached. Then air can be introduced, and the gas composition follows along the line SR.

In this case the flammability zone is avoided and a safe vessel preparation procedure is ensured.

So one approach is to continue the nitrogen flow until the vessel contains pure nitrogen that means you start from here and start filling the vessel with nitrogen and you will ultimately get 100% nitrogen. However, this will require lot of nitrogen and also it is expensive. So more efficient procedure is to do the following. Let us spill nitrogen up to point S and then let us start filling air and follow the path S R to come to the composition with pure air that means 79% nitrogen and 21% oxygen.

So in this case note that the flammability zone is completely avoided and the same vessel preparation procedure is ensured. So you start feeling nitrogen along the path S and then follow the path S R to pump in air and then reach the point R corresponding to pure air. This is how we can avoid the flammability region. Note that this is the flammability region here and we travel like this.

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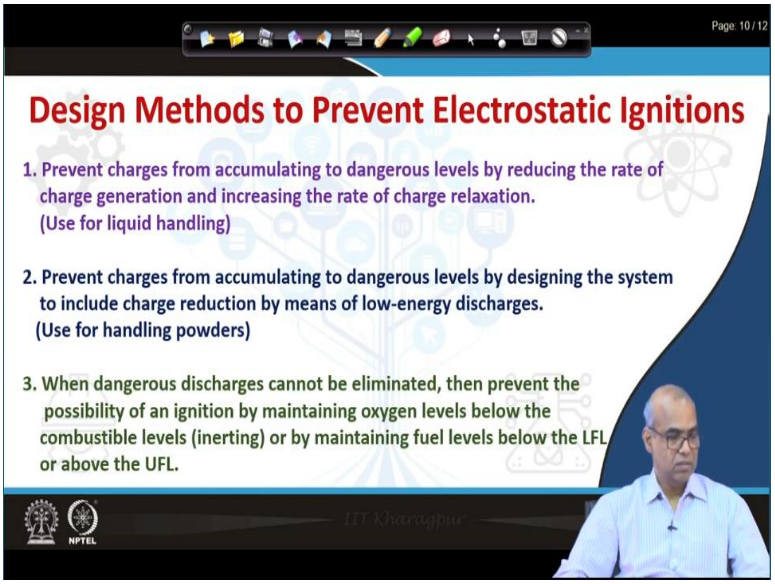

Design Methods to Prevent Electrostatic Ignitions

1. Prevent charges from accumulating to dangerous levels by reducing the rate of charge generation and increasing the rate of charge relaxation. (Use for liquid handling)
2. Prevent charges from accumulating to dangerous levels by designing the system to include charge reduction by means of low-energy discharges. (Use for handling powders)
3. When dangerous discharges cannot be eliminated, then prevent the possibility of an ignition by maintaining oxygen levels below the combustible levels (inerting) or by maintaining fuel levels below the LFL or above the UFL.

Finally, let us talk about few steps to prevent electrostatic ignitions. Basically we have to prevent charges from accumulating to dangerous levels, whether we are handling liquid or handling powders we have to prevent charges from accumulating to dangerous levels. In case of liquid handling prevent charges from accumulating to dangerous levels by reducing the rate of charge generation and increasing the rate of charge relaxation.

For kick for the case of handling powders prevent charges from accumulating to dangerous levels by designing the system to include charge reduction by means of low energy discharges. Now when the dangerous discharges cannot be eliminated then prevent the possibility of an ignition by maintaining oxygen levels below the combustible levels. By adopting inerting strategy or by maintaining fuel levels below the lower flammability rate or above the upper flammability rate.

That means you have to take the mixture to the non-flammable region. With this we stop our discussion here.