Chemical Process Safety
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Lecture 23 - Explosion & its Classification – 1

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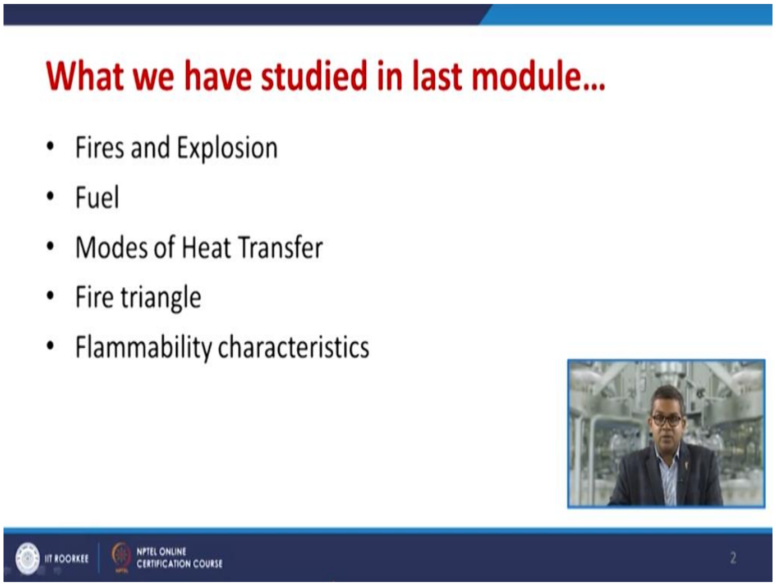

Welcome to the third module of Fire and Explosion. So up till now we have studied in the different modules about the fire and explosion, different type of fuels, what are the different kinds of modes of heat transfer through which fire can propagate. We have discussed about the fire triangle and different flammability characteristics.

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Now in this particular module we will study about the explosion and its classification, vapor cloud explosion.

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So explosion, it is an extremely dangerous thing and there are so many accidents they are attributed to because of explosion. In the history, in the chemical engineering history there are 2 major accidents; one is Flixborough and other one is the Jaipur accident. They took place just because of explosion.

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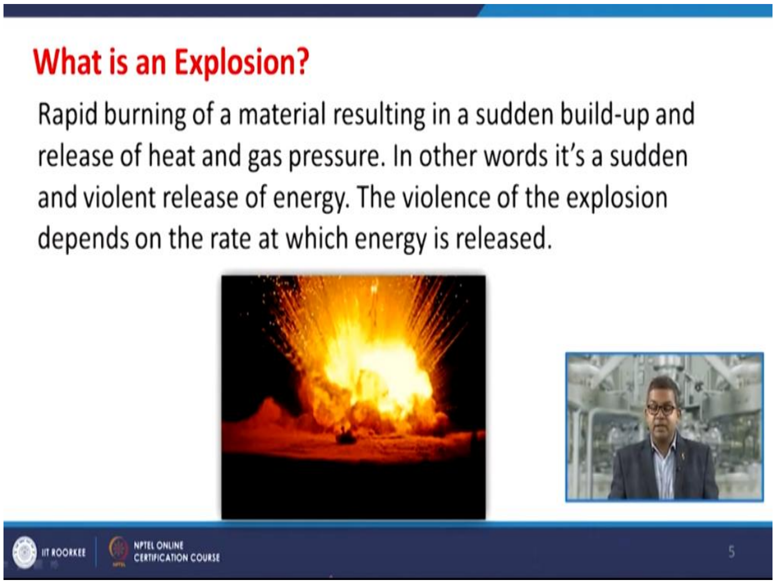

So question arises that what is an explosion? This is the definition of explosion: This is the rapid burning of a material resulting in sudden build-up and release of heat and gas pressure. In other words it is a sudden and violent release of energy, the violence of the explosion depends on the rate at which the energy is released. So sometimes fire may lead to explosion and sometimes it may not. When the fire is leading towards an explosion then the conditions are extremely dangerous.

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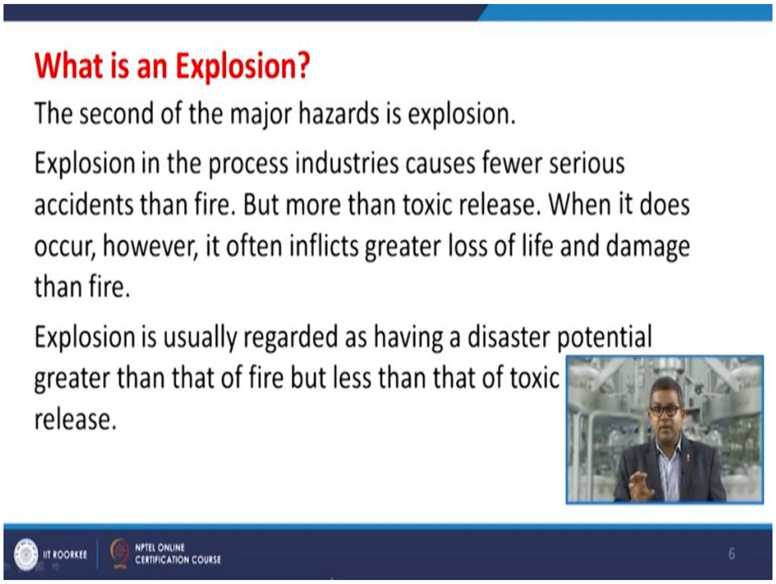

This is the second of the major hazard is explosion. The explosion in the process industries causes fewer serious accidents than fire but more than toxic release, so when it does occur however it often inflicts greater loss of life and damage than fire because sometimes the one additional thing in the explosion is that the generation of shockwaves. This can matches with the natural frequency of nearby building and all those building may get extremely damaged. So explosion is usually regarded as having a disaster potential greater than that of fire but less than that of toxic.

So in other modules we will discuss different case studies. We can see the toxic accident that is attributed to Bhopal is dangerous compared to the Jaipur accident or Flixborough accident. Now fire and explosion may be, you can say they are 2 sides of same coin, they both are based on strongly exothermic chemical reactions, usually the combustion in air.

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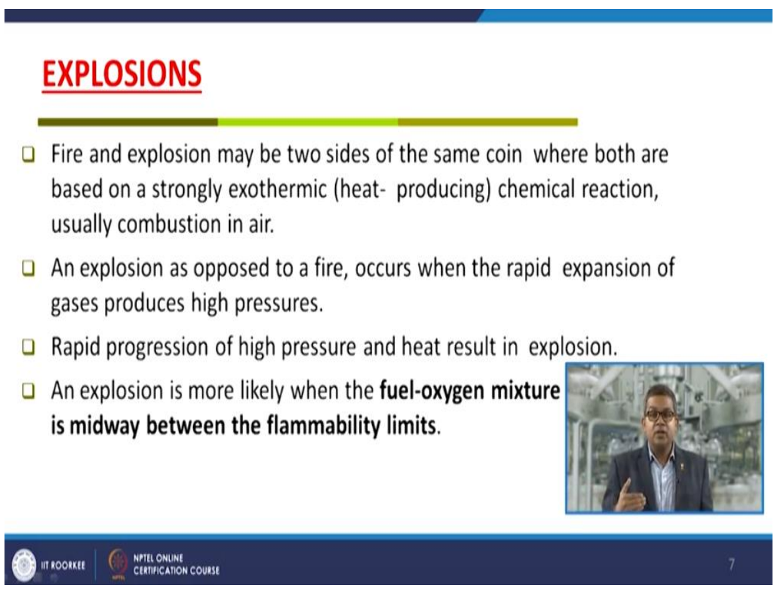

So explosion as opposed to a fire, when the rapid expansion of gases produces the higher pressure and this higher pressure through rapid propagation may result the explosion and may cause the generation of shockwaves which are again devastating. So an explosion is more likely when the fuel-oxygen mixture is midway between the flammability limit because in that particular case the fuel-oxygen mixture may escape to the atmosphere and it would not be, you would not be able to control it in which direction because usually it propagates towards the direction of wind inversion. So you will not be able to apply all your safety measures to that uncontrolled escape of this vapor cloud.

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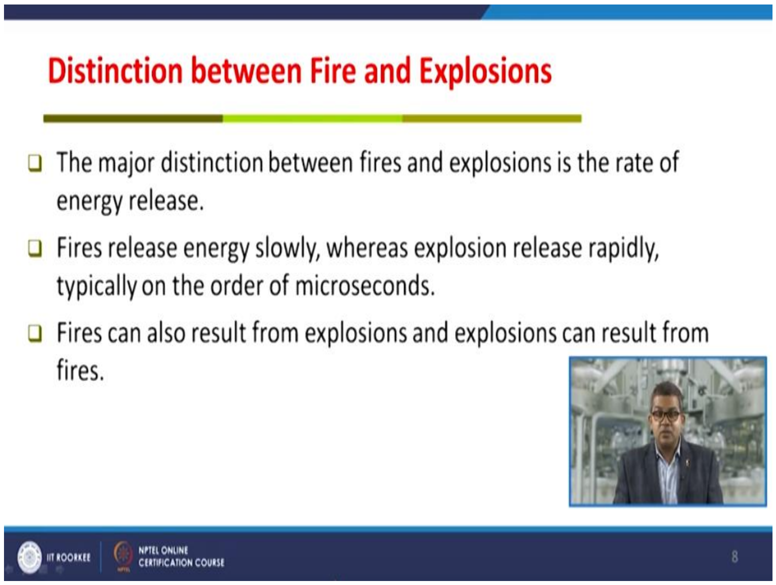

The measure distinction, when we talk about distinction between the fire and explosion, the major distinction between fire and explosion is the rate of energy release. Fire releases energy slowly whereas explosion releases rapidly, typically in the order of microseconds. So in very small time duration you can experience the sudden release of extreme amount of energy. So fire can result from explosion and explosion can result from fire, so that is why we have said that more or less these are the 2 sides of a coin.

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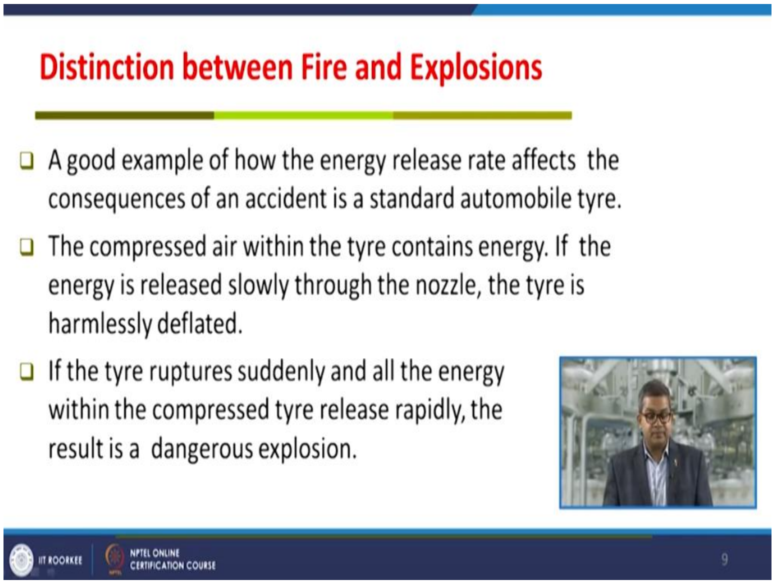

A good example of how the energy release rate affects the consequences of an accident is a standard automobile tyre. You may experience that when burst, the compressed air within the tyre contains huge quantum of energy and if energy is released slowly through the nozzle the tyre is harmlessly deflated and if tyre ruptures suddenly then all energy within the compressed tyre releases rapidly and the result is a dangerous explosion. And you sometimes may experience the large noise as well as, all of sudden then you can see the dust and other dust particles they are escaping when this tyre ruptures. So this is the difference between the fire and explosion. You can extrapolate the things in term of fire and explosion.

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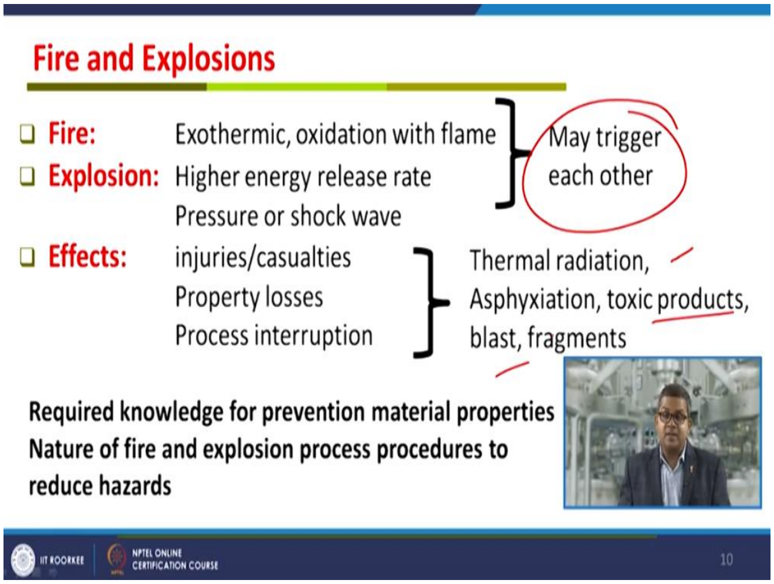

And just the fire is exothermic oxidation with the flame. Explosion, the higher energy release rate, pressure or a shockwave and this may trigger each other. The usual effects are injuries, casualties, property losses, process interruption. This may be because of thermal radiation, toxic products, blast, fragments, etc. So required knowledge for prevention material properties obviously, the nature of fire and explosion process procedure to reduce the hazard. So you must know that what kind fire is there and how it propagates, what kind of explosion is there, how it can propagates.

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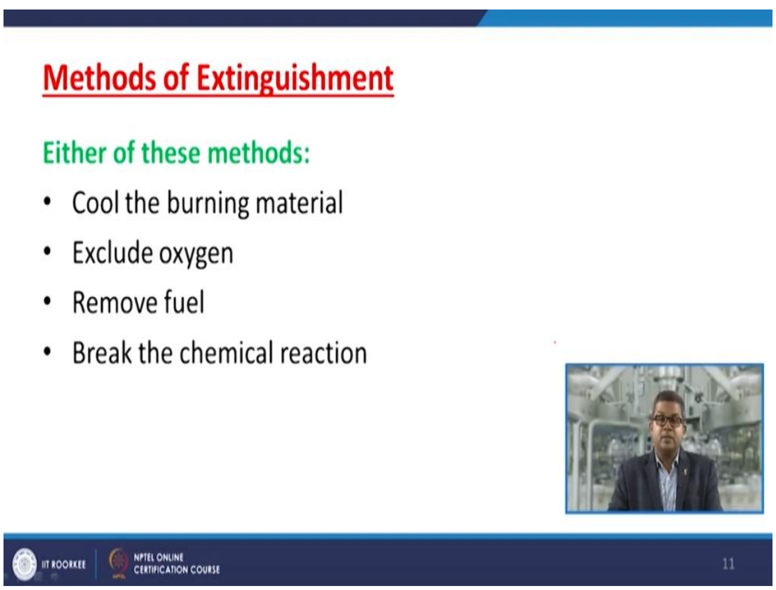

So when we deal with the method of extinguishment, then you must know the either of 3 methods: How to cool the burning material, how to exclude the oxygen, how to remove the fuel and how to break the chemical reactions.

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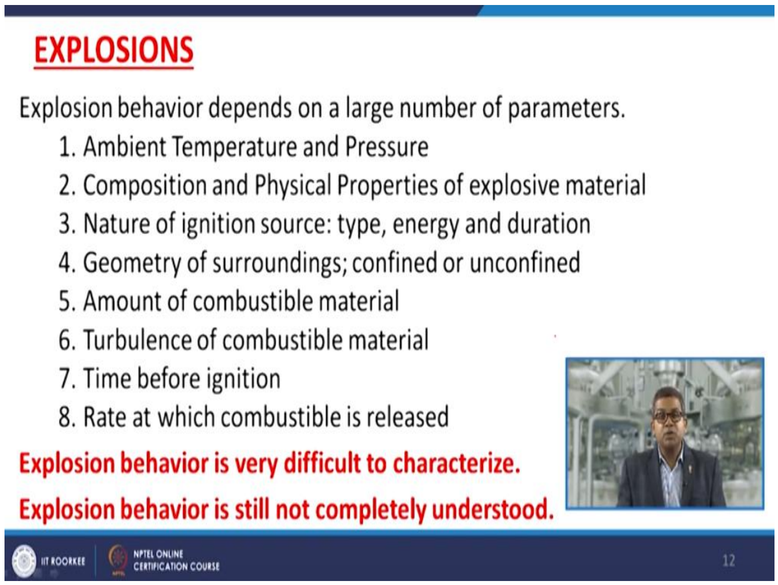

Now coming back to explosion, usually when we talk about because we have discussed a lot about the fire, so when we talk about the explosion the explosion behavior depends on large numbers of parameters and we have enlisted all the parameters. Number 1 is the ambient temperature and pressure. So you must know that what is the ambient temperature and pressure. In the previous module we have discussed the temperature and pressure on LFL and UFL, so if you are having the adequate knowledge, so in case of eventuality you can avoid the further accidents.

You must know the composition and physical properties of explosive materials. For this you must know that what is the importance of MSDS, so you cannot treat the all hydrocarbons or all combustible materials in a single platform. You must know what will be the delta H of each and every one. Nature of ignition sources: type, energy, duration this is again important. In the previous module we have discussed about the ignition sources.

So which kind of source of ignition may be present in the workplace in case of any problem, how much energy is being there and what would be the duration, millisecond, seconds etc? And sometimes you may experience that if you go to the petrol pump station then it is advisable not to use your mobile phones, it is advisable not to lit the cigarettes etc, it is always advisable to be very careful in that particular zone. Because sometimes the little spark being generated from the mobile phone may be extremely harmful and again one more advisory is that if you are working in a kitchen and some by any means LPG releases then it is always advisable not to turn off or turn on any kind of electric switch whether it is a ventilation or the electrical switch.

The reason is that the small spark may be extremely dangerous. Then you must know the geometry of surrounding if it is confined or unconfined, remember the confined geometry is somehow favorable. The reason is that whenever you are working, supposed I am working in a pool of hexane, I know that hexane is flammable, it may create a problem, it may form a flammable mixture, so my outside environment is extremely safe by the use of safety devices.

So I am very much aware about what kind of safety devices are there. Now by any means by the generation of excessive pressure, by the generation of any means these hexane vapors they escape to the atmosphere, and because of the wind inversion, because of the wind velocity it may go to some other places. Adequate quantity of oxygen is available through air, so it may form the combustible mixture and you do not have any clue about that what kind of different sources of ignition be there. Sometimes somebody starts his car, sometimes somebody start his scooter or he may be using the mobile phone, then definitely the adequate source of ignition they are available.

So you must know about the importance of geometry of surrounding. You must have a knowledge about the amount of combustible mixture. Suppose I am working over here with the pool of hexane and say 1000 kiloliter of hexane is there, then how much quantity of hexane is escaped to the atmosphere so that I can devise or I can actuate my safety devices accordingly? Turbulence of combustion material, again it is equally important that how much quantity of air being mixed with this combustible material. You must know about or you must analyze the time before ignition, the reason is that it gives you enough idea so that you can anticipate that how much dilution is present.

How your combustible, released combustible material is diluted because of the presence of atmospheric air? The reason is that again LFL and UFL comes into the picture, if adequate oxygen is there then definitely they will form the combustion but if more than required oxygen is there then definitely the mixture will be to lean to catch fire. So suppose again I am working in this reactor with the hexane or LPG or any combustible material, because some thermal runaway reaction the combustible material releases to the atmosphere, at this particular point of time it may not catch the fire but where it goes at that particular point of time it may catch fire. So you must know that rate at which combustible is released.

So all these eight parameters, they are extremely important to discuss the or to analyze the combustible behavior. Now, why we are discussing this combustible behavior a priori? the reason is that whenever any kind of fire took place then definitely we must analyze or we perform the accidental investigation in these lines. Now remember one thing before go ahead that explosion behavior is very difficult to characterize and simultaneously the explosion behavior is still not completely understood. So these 2 things must be, you must aware about these 2 things.

Now before we go ahead with the explosion, the question arises, are we in a position to classify the explosion? Yes, we can classify the explosion.

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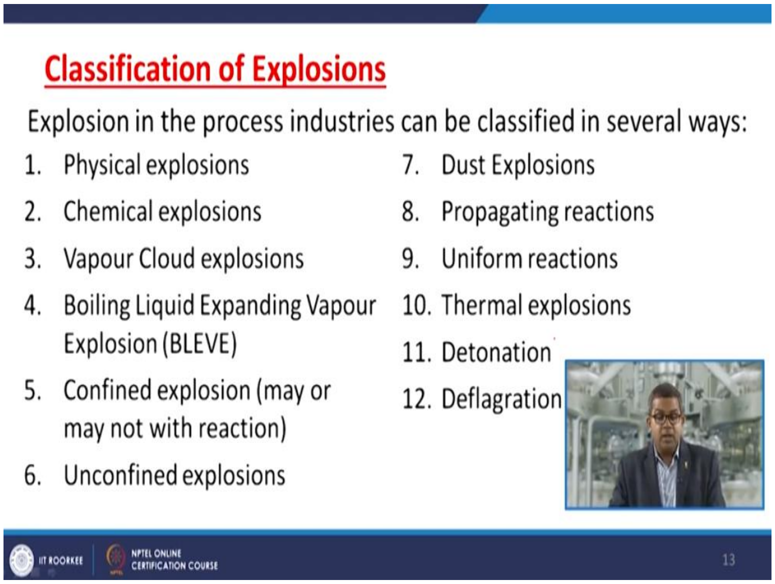

So explosion in the process industry can be classified in several ways: physical explosion, chemical explosion, vapor cloud explosion, Boiling Liquid Expanding Vapor Explosion (BLEVE), confined explosion may or may not followed by the reaction, unconfined explosion, dust explosion, propagating reactions, uniform reactions, thermal explosions, detonation and deflagration. So we will take up one by one.

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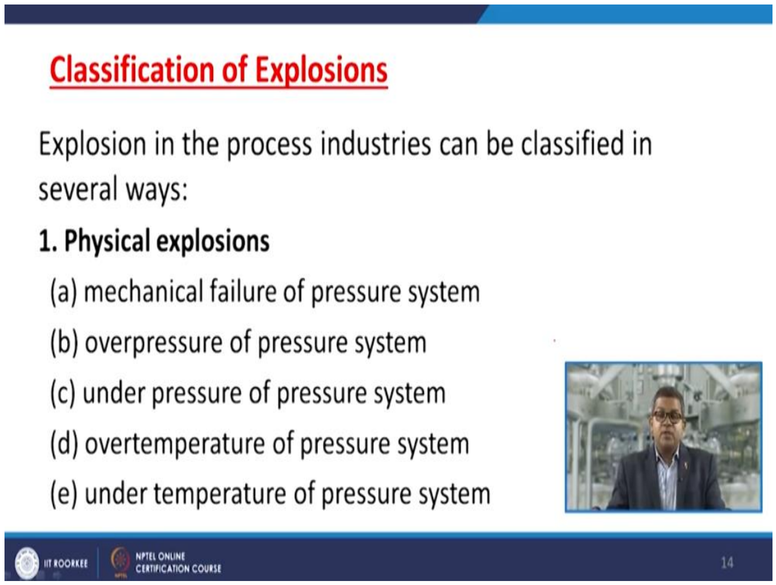

The physical explosion, this may be just attributed to the mechanical failure of pressure system, overpressure of pressure system, under pressure of pressure system, over-temperature of pressure system, under temperature of pressure system. So chemical reactions they do play a very vital role because the pressure and temperature both are integral part of any chemical reaction.

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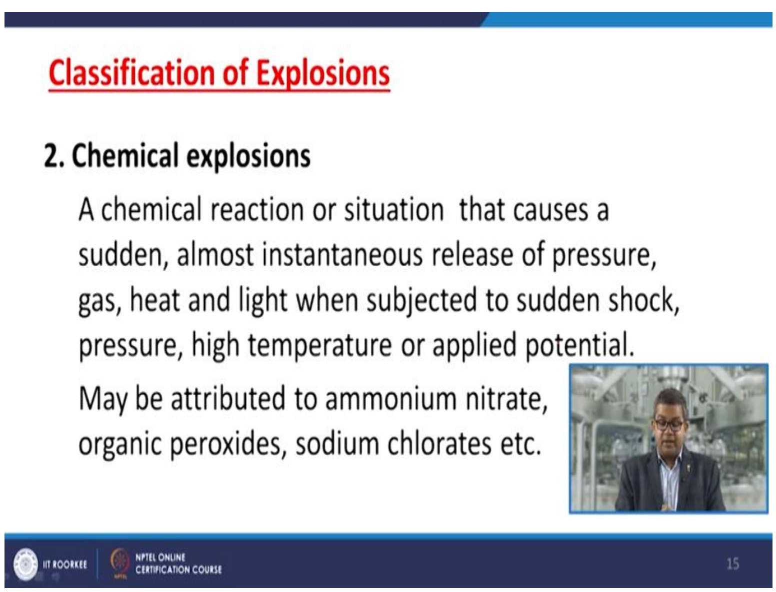

Then chemical explosion, a chemical reaction or situation that causes a sudden almost instantaneous release of pressure, gas, heat or light when subjected to sudden shock, high temperature or applied potential. This may be attributed to the ammonium nitrate, organic peroxides, sodium chloride etc; so you must know that what is the efficacy of these chemical explosions.

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The vapor cloud explosion, very common and extremely important. The explosion resulting from the ignition of a cloud of flammable vapor, gas or mist in which flame speeds accelerate to sufficiently high velocity to produce significant overpressure. This is extremely dangerous, lot of accidents took place in history those who are attributed to vapor cloud explosion.

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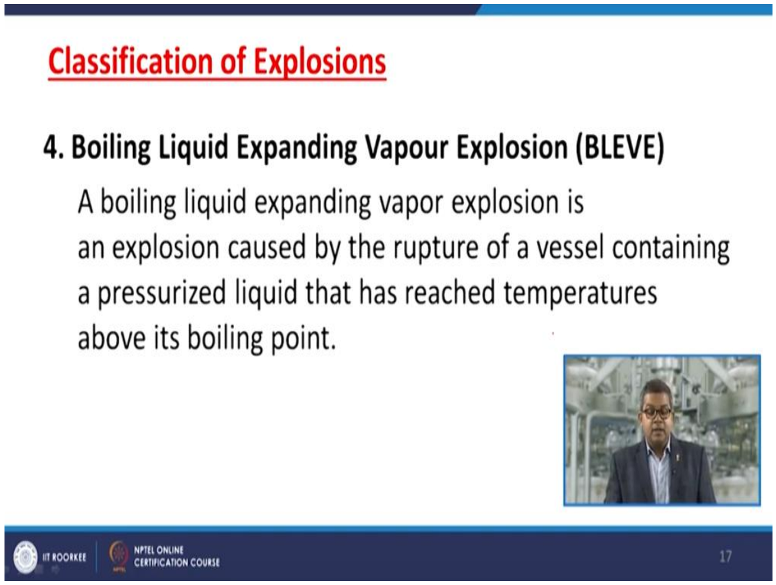

Then boiling liquid expanding vapor explosion, BLEVE, a boiling liquid expanding vapor explosion is an explosion caused by the rupture of a vessel containing a pressurized liquid that has reached temperature above its boiling point. We will discuss this is in subsequent slides.

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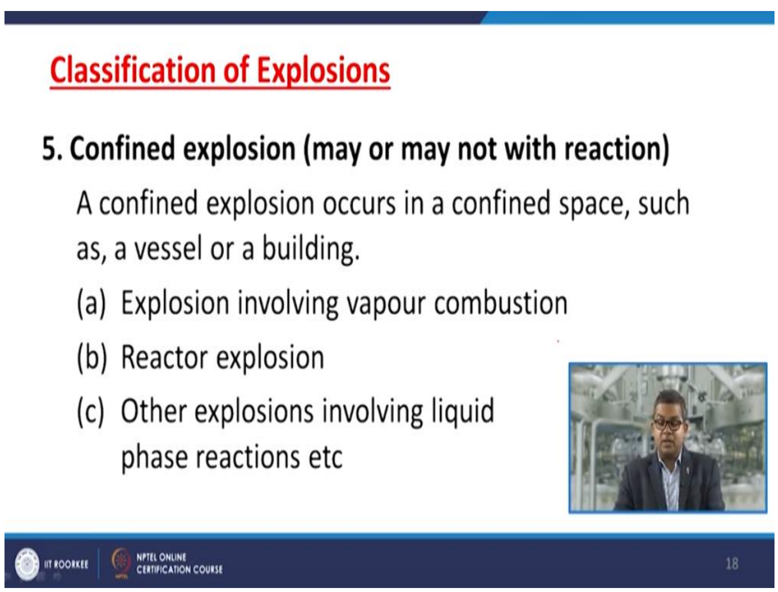

The confined explosion may or may not with reaction, a confined explosion occurs in a confined space such as a vessel or a building. Remember, every time whenever we are anticipating the chance of any confined explosion the we always equip with the barrier safety devices, so this explosion involve the vapor combustion, reactor explosion, other explosion involving the liquid phase reactions etc.

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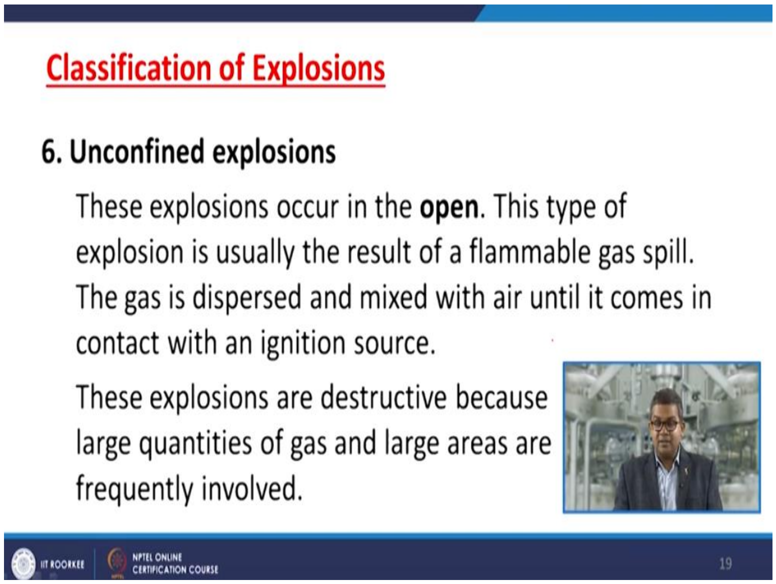

Another classification is attributed to the unconfined explosion, these explosions occur in open and this type of explosion is usually result of a flammable gas spill maybe through the pressurized or un-pressurized vessel. The gas dispersed and mixed with air until it comes in contact with the source of ignition. These explosions are destructive in nature because large quantity of gas and large areas are frequently involved and practically you are handicapped with the non-availability of your safety devices in those areas where it blown up.

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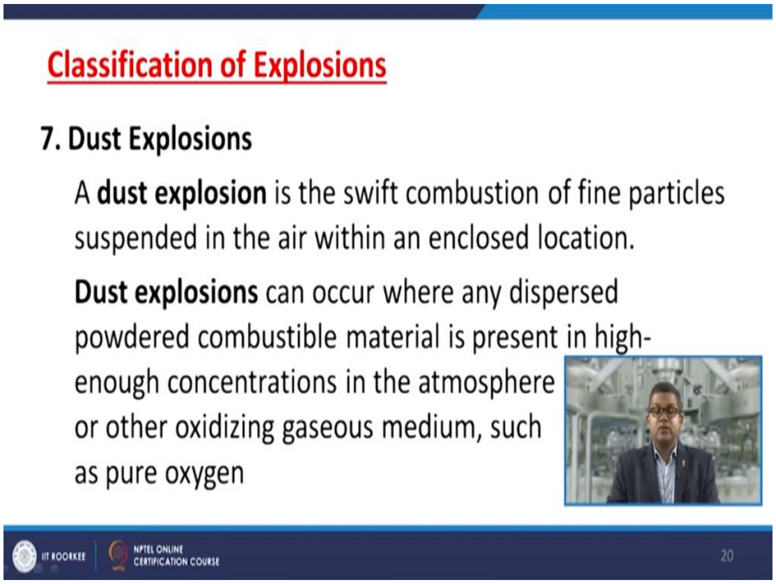

Next is your dust explosion, dust explosion is a swift combustion of fine particles suspended in the air within an enclosed location. Now dust explosion can occur where any dispersed powder, combustible material is present in high-enough concentrations in atmosphere or other oxidizing gaseous medium, such as pure oxygen. So again it is very important, and again there are so many accident in history, they took placed just because of the dust explosion.

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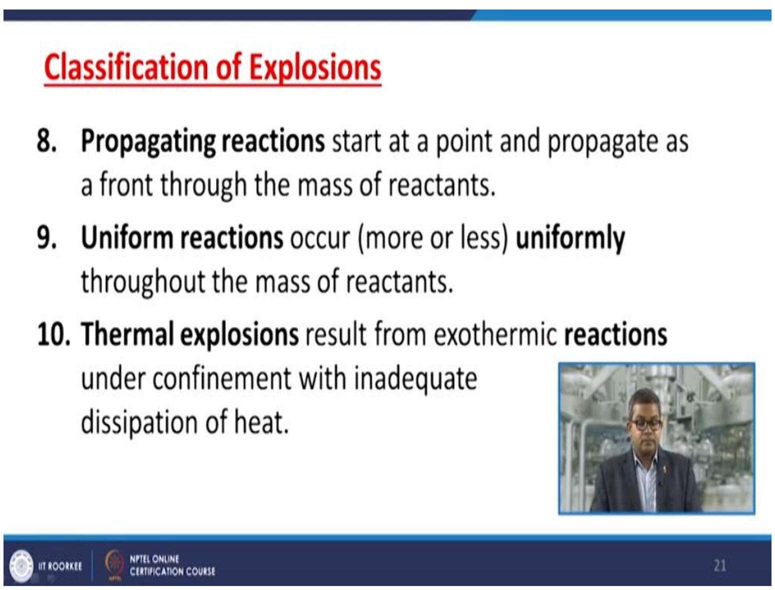

Next is the propagating reactions start at a point and propagate as a front through the mass of reactants. Sometimes explosion may attributed to the uniform reactions, the uniform reactions occur more or less uniformly throughout the mass of reactants. The thermal explosions, they are results from the exothermic reactions under confinement with inadequate dissipation of heat.

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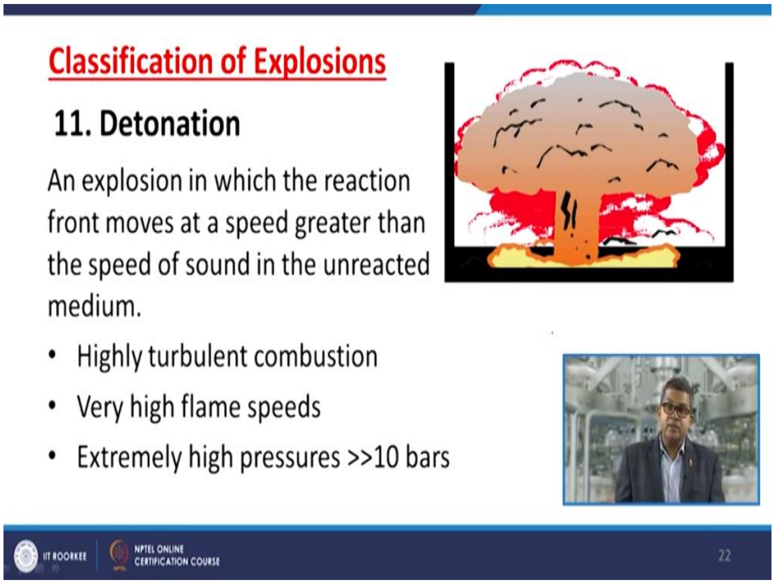

The detonation, this is again very destructive and very important. An explosion in which the reaction front moves at a speed greater than the speed of sound in the unreacted medium: a very high highly turbulent combustion, very high flame speeds and extremely high pressure. Sometimes it is more than 10 bars and there are so many accidents in the history they are involved with multiple classes of explosion like vapor cloud explosion led to the detonation, sometimes BLEVE led to the detonation.

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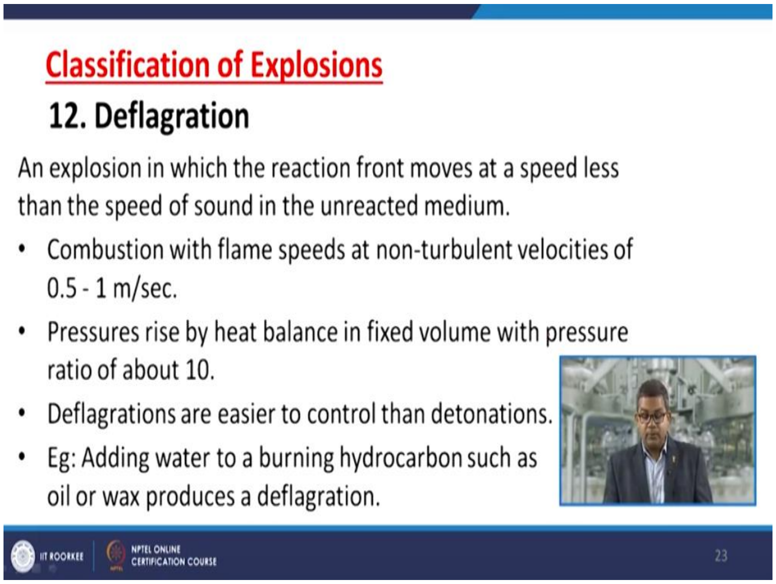

The last in these classes, the deflagration, an explosion in which the reaction front moves at a speed less than the speed of sound in the unreacted medium. In detonation the reaction front moves at a speed more than the sound of a speed in the unreacted medium, the combustion with flame speed at non-turbulent velocities of maybe say 0.5 to 1 meter per second, pressure rise by heat balance in fixed volume with pressure ratio of about 10. Deflagrations they are easier to control than detonation, usually by example, examples are adding water to the burning hydrocarbon such as oil or wax produces a deflagration.

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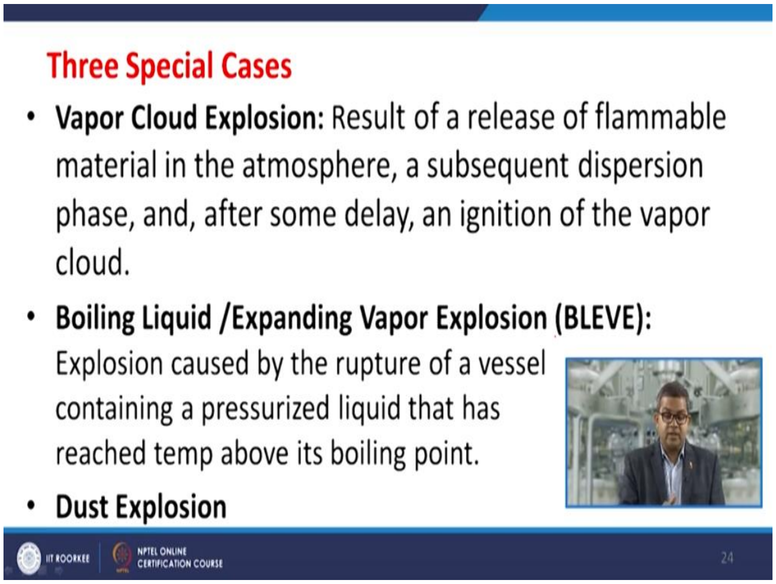

Now in subsequent slides or subsequent modules we will discuss 3 special cases or 3 special classification streams: One is vapor cloud explosion, this result of release flammable material in the atmosphere, a subsequent dispersion phase and after some delay an ignition of the vapor cloud. We will discuss these cases in detail. The boiling liquid expanding vapor explosion, BLEVE, explosion caused by the rupture of a vessel containing a pressurized liquid that has reached temperature above its boiling point, we will discuss this one. And third one is the dust explosion, so we will discuss 3 special classification among all 12 classification streams, we will discuss these three.

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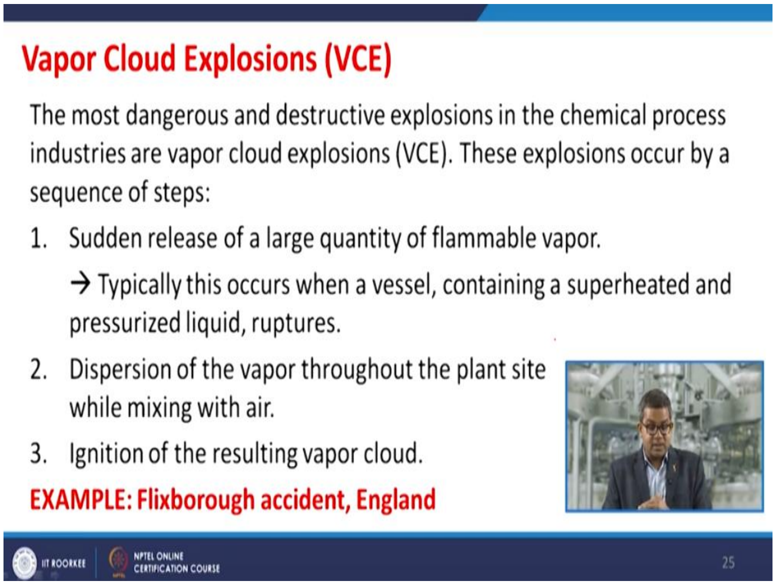

Now vapor cloud explosion, this is one of the most dangerous and destructive explosion in chemical process industries. This explosion occur by a sequence of steps. Just try to understand these sequences: There is a sudden release of large quantity of flammable vapor. Suppose I am working in the pool of hexane, this is the closed pool of hexane and we know that the boiling point of hexane is around from 65 to 70 degree Celsius based on the purity of a material. So I am working say around at 110 or 125 degree Celsius, it is a closed vessel pressurized vessel.

So sudden release of a large of quantity of flammable vapor, maybe the tones of hexane, typically this occurs when vessel containing the superheated and a pressurized liquid, it ruptures. Then dispersion of vapor throughout the plant site while mixing with air, so this pool of hexane by any means may be through safety valve, may be because of some crack in the pressure vessel it dispersed to the atmosphere where it forms, where it comes into contact with atmospheric oxygen and forms the flammable mixture.

And the third step is the ignition, with ignition of the resulting vapor cloud maybe by any chance, maybe because of the spark generated through the shoe nails, maybe the dry hair, maybe the silky cloths etc, the combustible mixture ignites because these sources of ignition are N. So ignition of this resulting vapor cloud, so this is a 3 step process, we will take up a case study of Flixborough which took place under the class of vapor cloud explosion.

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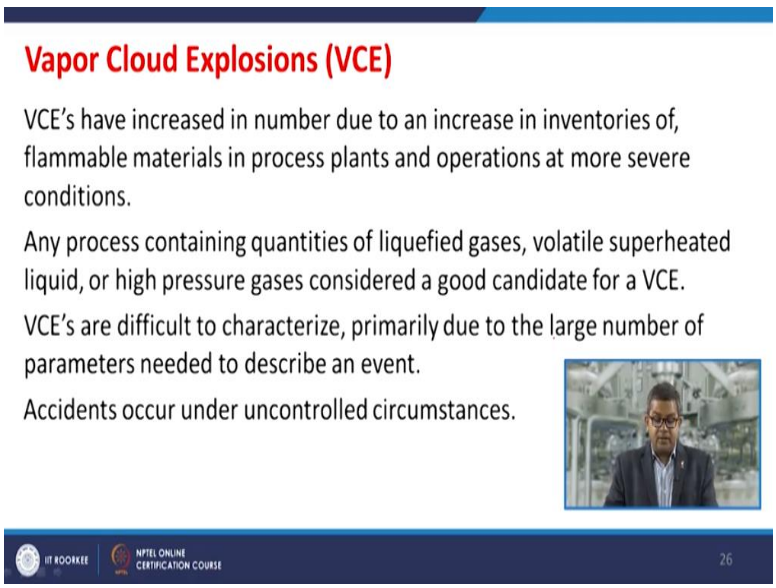

Now VCE or vapor cloud explosions, they are increasing in numbers due to the increase in inventories of flammable material in the process plant and operations at most severe or more severe conditions. So they are increasing day-by-day, so thereby the importance safety devices are also increasing day-by-day. So any process containing quantities of liquefied gases, volatile superheated liquid or high pressure gases considered a very good candidate for vapor cloud explosion. Now VCEs they are difficult to characterize primarily due to the large number of parameters needed to describe an event. Now accident under uncontrolled circumstances, they are also attributed to the vapor cloud explosion.

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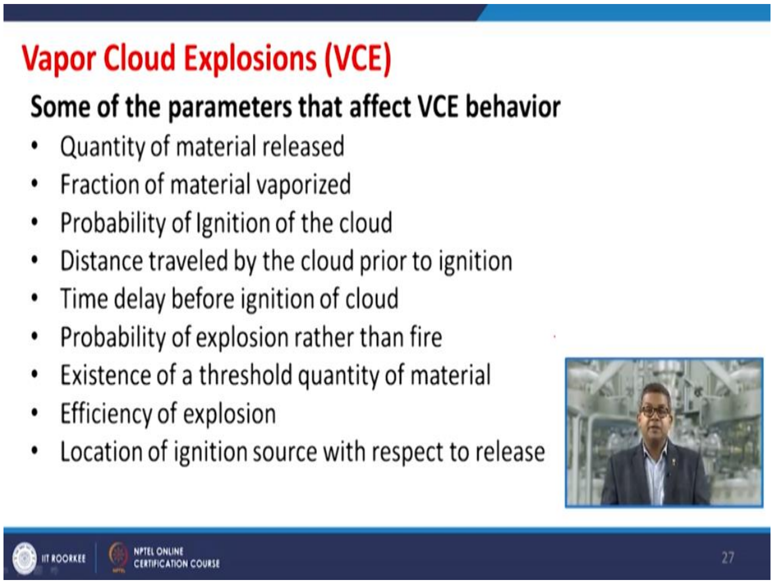

So and we have discussed that there are large number of parameters they have attributed to the vapor cloud explosion. Now we can have, looked at what are the different parameters those affect vapor cloud explosion behavior. Number one is that how much quantity of the material released. Supposed I am here with working with the pressure vessel having the amount of hexane say 100 kiloliter and almost 500 kiloliter is escaped, so must know that how much quantity of the material released, what of the fraction of the material is vaporized because the only vaporized material can participate in fire or ignition or it can form the combustible mixture.

But simultaneously whenever it is ignited it produces sufficient quantity of material to form the additional vapors which are not being vaporized, then what is the probability of ignition of the cloud which is being escaped from your workplace? Then distance travelled by the cloud prior ignition, the reason is that how much time is given to the cloud for the dilution or for the dispersion or for the formation because if it is escapes from this particular point where I am working the concentration would be on the higher side, concentration of hexane would be on the higher side, so probably it may be beyond UFL.

So when it is it released to the atmosphere then at what particular point of time or a distance it matches the range of LFL and UFL? And simultaneously it is again required to know that how much time it would take to neutralize the effect of LFL and UFL range, because if it is too diluted or the concentration of the fuel is very less, then definitely it would not be ignite whatsoever the source of ignition is there. So you must know that distance travelled by the cloud prior to ignition and time delay before ignition of the cloud so that you can analyze that what is the greater, again there are other parameters like density etc, they are again very crucial.

Then probability of explosion rather than fire, because the fire may lead to explosion and explosion may lead to fire. Then existence of a threshold quantity of material, again this is attributed to the LFL and UFL. Then what is efficiency of the explosion? See, if it is extremely pressurized vessel then the explosion may lead to the formation of shockwaves, nearby buildings may get collapsed and if these nearby building or establishments they do have the storage of this flammable material then again the problem will be more destructive. The same happened at the Jaipur accident.

Then location of ignition source with respect to release, we must know that at what location was there for that source of ignition. See, why I am telling you this, suppose by any means it releases and it goes to say 100 meter apart or 200 meter apart, remember this particular zone is filled with your all kind of safety devices but 100 meter or 200 meter apart you would not find any safety devices, and somebody by any chance because they do not know that what kind of scenario is, by any chance they start their car, so source of ignition is there flammable mixture is there, there may be a chance the cloud may catches fire. So you must know that what is the location of this ignition source.

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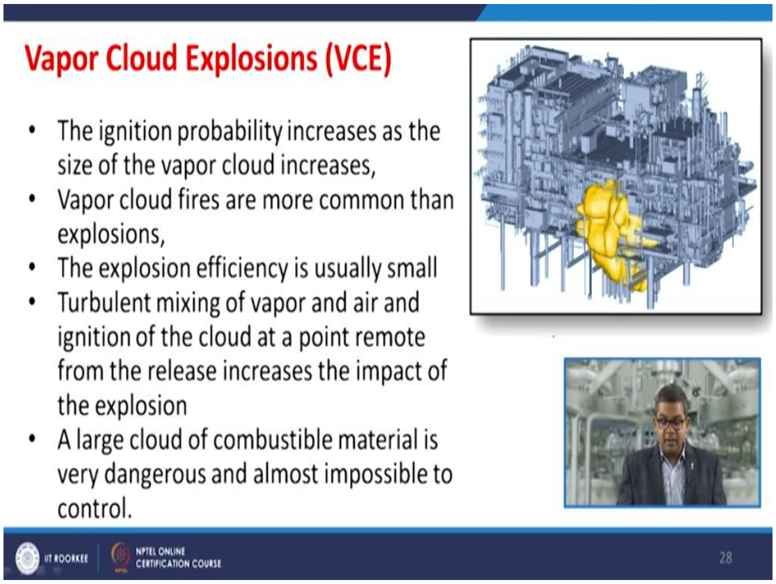

Now ignition probability increases as the size of the vapor cloud increases because if it is on the larger side then definitely it is very difficult to eliminate the source of ignition at that particular point. Now vapor cloud fires are more common than the explosion, obviously the explosion efficiency is usually small and the turbulent mixing of vapor and air and ignition of the cloud at a point remote from the release increases the impact of the explosion. A large cloud of combustible material is very dangerous and almost impossible to control and the same happened in Jaipur accident.

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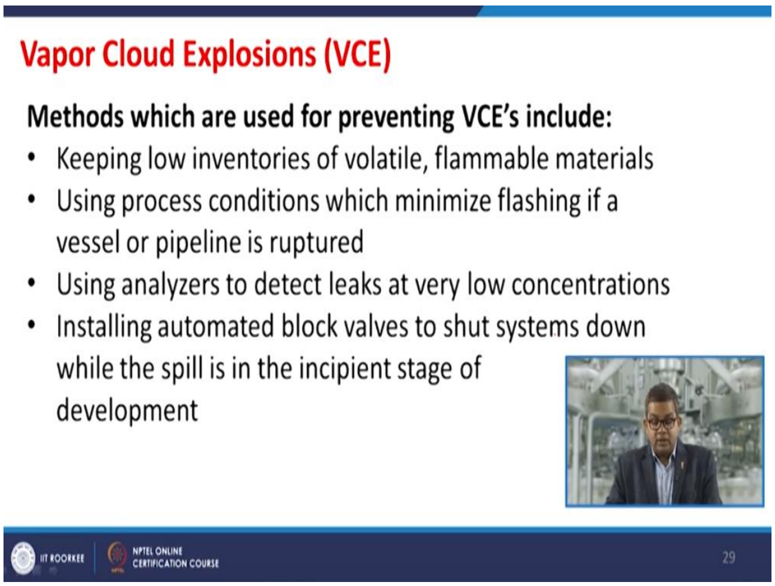

Now we can discuss that various methods through which we can use to prevent vapor cloud explosion and this includes the keeping low inventories of volatile flammable materials. Obviously, it is always advisable you reduce your warehouse and you reduce the number of volatile and you use only up to a certain limit and Flixborough they stored a huge quantum flammable material in their establishment. So you keep low inventories, it is not only reduces your safety problem but also reduces the economics, economic burden involved in warehousing.

Using process conditions which minimize flashing if a vessel or pipeline is ruptured, recall the industrial hygiene where we discussed a lot in such aspect. Using analyzers to detect leak at a very low concentration, though it is very costly but again for the safety of your plant it is always advisable. Installing automated block valves to shut the system down while the spill is in the incipient stage of development so that you can cut the supply of the fuel to the danger zone.

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Now let us have a look at what happens to a vapor cloud. Now, simultaneously we can have look a look of this particular diagram. The cloud spreads from too rich, through a flammable range to too lean, that is subjected to the availability of air. So first hand, edges start to burn through the deflagration, the steady state combustion and enough vapor is being generated and enough heat is being liberated. Now this cloud disperses through a natural convection, because of heat generation the density difference usually takes place and this density difference lead to the natural convection of this dispersion. Now flame velocity will increase with containment and turbulence.

Now if velocity is high enough, cloud will detonate like this, so the cloud will burst just like anything. Now if cloud is small enough with a little confinement it cannot explode. The reason is that you will be able you will be in position to control it. So in this particular module we have discussed the various classification streams of explosion and we have taken 3 special cases, vapor cloud explosion, BLEVE, and dust explosion and we have discussed the vapor cloud explosion. Thank you very much.