NPTEL

NPTEL ONLINE CERTIFICATION COURSE

Health, Safety & Environmental Management in Offshore and Petroleum engineering (HSE)

Module 2:
Accident modeling, Risk assessment & Management
Lecture 4: Explosion release models

Friends welcome to the fourth lecture on module 2 which is focusing on accident modeling risk assessment and management in this lecture in HSE course we will talk about the explosion release modeling.

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Let us quickly understand what do we mean by explosion explosions are generally indications measures of sound noise and sudden disruption of objects at the site expression means violent bursting or driving out of objects that the destructive force so therefore an important concept in explosion is that what is the quantum of energy being released when a material or a chemical mixture is exploded.

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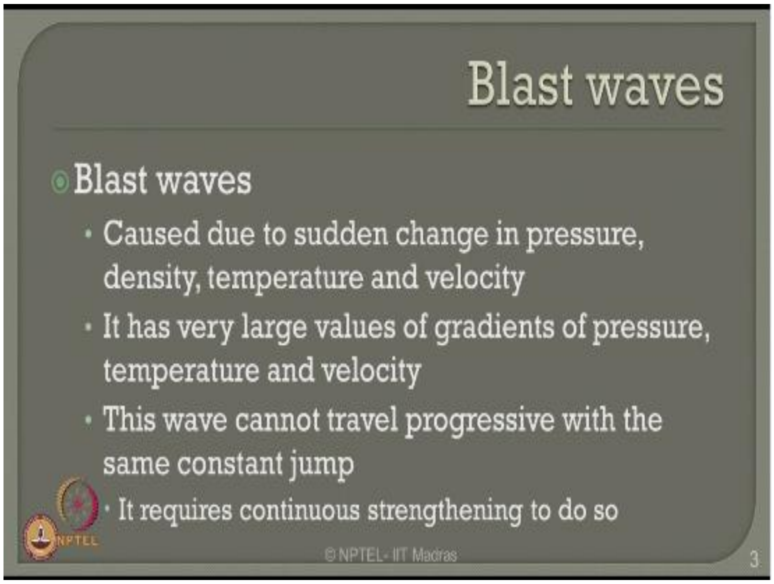

So there are two types of waves which causes explosion one is called as a blast wave the other one is called as a shockwave let us see what do we mean by a blast wave blast wave, blast waves are cost due to sudden change impression, density, temperature and velocity it has a very large value of gradients of pressure temperature and velocity because a rise of the change is very steep this wave cannot travel progressive in the same constant jump therefore friends it is easy and this advantageous for us to understand that blast waves are decreasing in nature they will decline as the time progresses.

However if the blast wave is supported by an external source then the continuous progression of this wave is possible with the same intensity therefore it requires otherwise a continuous strengthening agency to progress in the positive direction with the same amount of amplitude.

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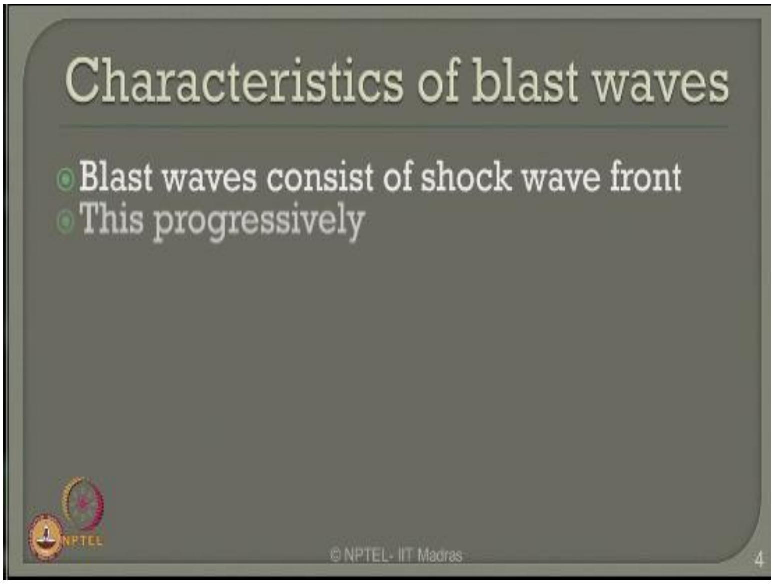

What are the characteristics of blast waves blast waves essentially consist of shock wave front.

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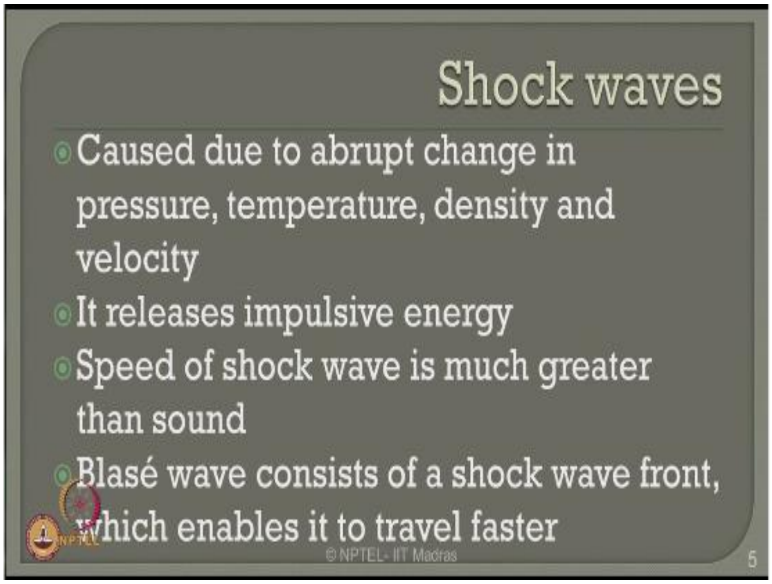

This progressively happens when the shock wave is projected another question comes what do you mean by shock waves shock waves are caused due to abrupt change in pressure, temperature, density and velocity it releases impulsive energy very fast the speed of shock wave is much greater than that of sound therefore it travels much faster in the medium when reaches and creates destruction as early as possible blast wave consists of shock wave front which enables it to travel faster that is the reason why blast waves also traveled faster because the wave front of blast waves is a shockwave front.

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Let us quickly see what are the possible types of explosions which can occur in a chemical plant. Types of explosions are generally categorized according to the mode of energy they are releasing naturally-occurring explosion, intentional explosion, accidental explosion.

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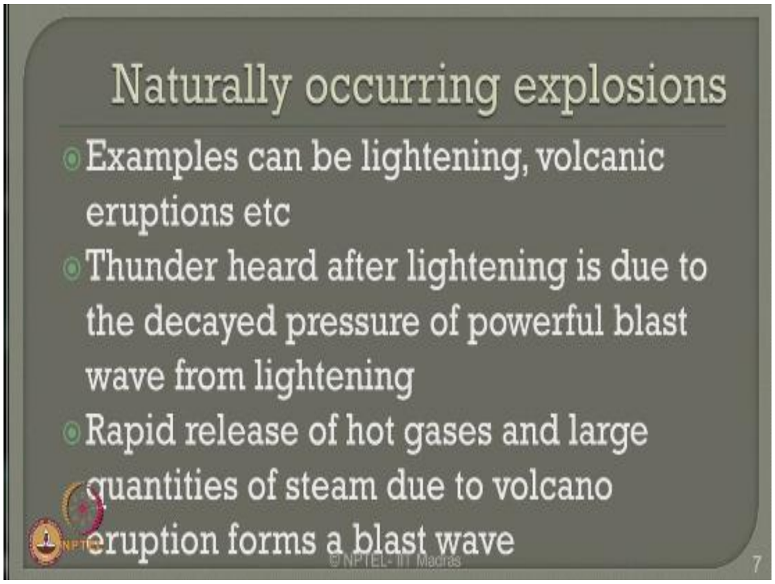

The naturally occurring explosions are can be seen as examples that arise from lightening volcanic eruptions etc… the Thunder heard after lightening is due to the decayed pressure of powerful blast wave which is arising from the lightning the rapid release of hot gases and large quantities of steam due to volcano eruption forms of blast wave.

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There are the second categories called intentional explosions they can be further classified as constructive explosions. Explosions for engineering applications and destructive applications constructive applications can be for blasting of rocks they are essentially required when you construct tunneling road construction dam and bridge pier construction etc… you may have to blast the rocks for effective deeper foundations therefore we also do blasting which is also a form of explosion which is essentially meant for constructive applications.

There are another advanced techniques available which are used in the reason past for controlled blasting so essential problem in case of such blasting case the free throw away material in the atmosphere which can cause damage to the people around which can also cause destruction to the objects located around now control blasting can prevent the flying of objects which is occurring because of blasting which is generally practiced in modern construction techniques these days.

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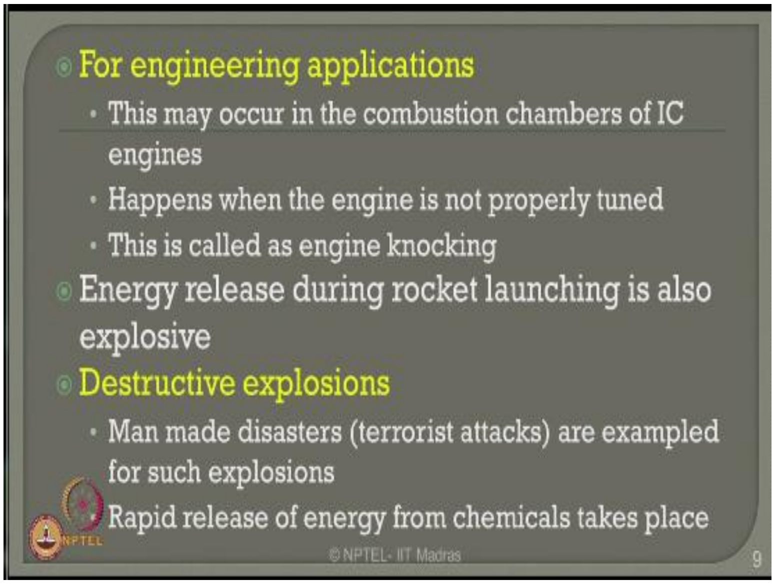

You can also do explosions for engineering applications this may occur in the combustion chambers of internal combustion engines it happens when the engine is not properly tuned technically this is what we call as engine knocking the energy in such situations are released during rocket launching is also a time of explosive which is for engineering applications the third category is what we call destructive explosion there are man-made disasters which are otherwise terrorist attacks which are examples of such explosions received in rapid release of energy which is from the chemicals which are exploded which are located in the place of explosions.

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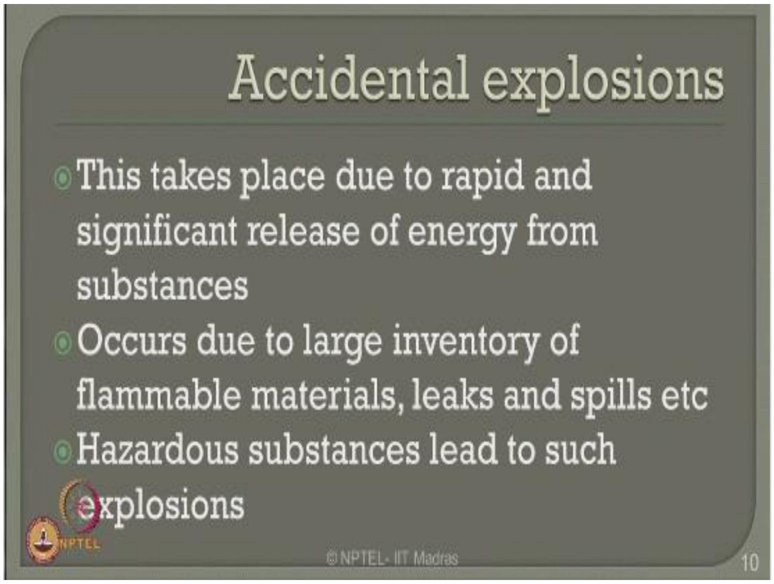

There are something called accidental explosions this takes place due to rapid and significant release of energy from the substances it occurs due to large inventory of flammable materials leak and oil spills etc…this is a very common type of explosion which generally happens in oil and gas production and drilling platforms essentially the hazarded substances or the inventory of hazardous substances present in the platform or the offshore drilling rig leads to such explosions.

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Explosions can also be classified further based on condensed phase thermal explosion gas phase confined explosion unconfined explosion boiling liquid expanding vapor explosion what we call BLEVE dust explosion, physical explosion and atmospheric dispersion which is also a form of or a kind of explosion. Nuclear explosion is of course a rare phenomena but however the disaster cost because of these explosions or very catastrophic and the societal damage arising from such are very severe.

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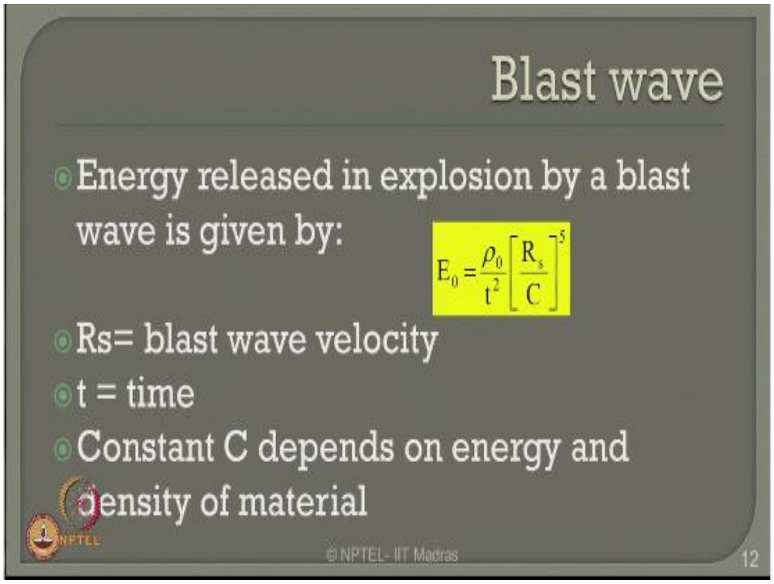

As we just now saw in a case of explosion it has got two kinds of waves the blast wave and the shockwave a shock wave enables a blast wave to proceed further in the progressive direction in terms of time so in both the cases the most important quantity which is to be measured is the energy released which is given me the equation shown in the slide the energy released in explosion by a blast wave is given by this equation where ρ_0 is the density of the material Rs is the blast wave velocity t of course the time. And C is a constant which depends on the energy and density of the material.

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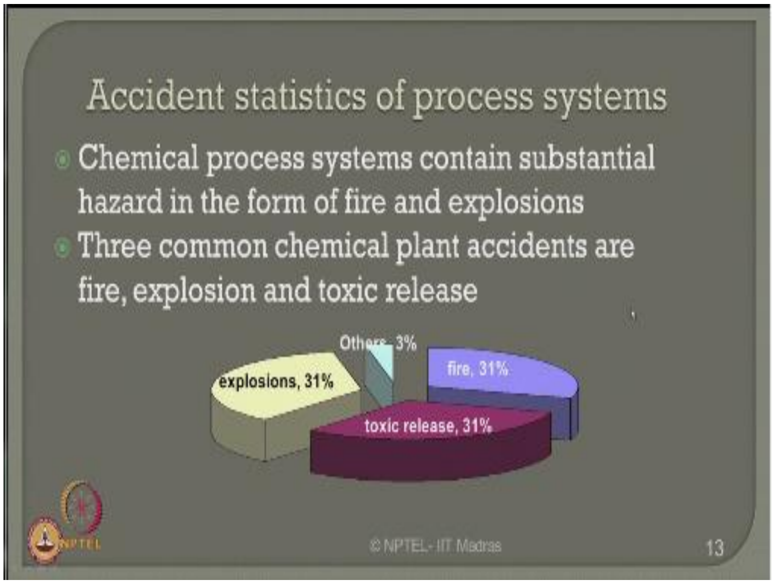

Let us quickly see the accident statistics of any process system. Chemical process systems contain substantial hazard material in the form of fire and explosion on the other hand the inventory which is stopped in the plant or the chemical process industries do have tendency of catching either fire or they can result in explosions three common chemical plant accidents generally or identified in the literature as fire explosion and toxic release however in the last lectures we understood how to model the toxic release an example of chemical exposure index which results in the ERPG guidelines.

And also the hazard distances has been given as example problems in the last lectures fire and explosion or one of the destructive and undesirable outcome of chemical plant accidents. If you look at the statistics available in the literature the literature shows that essentially chemical plant accidents has received incidences in the past mainly from explosions toxic release and fire however accidents cost in chemical plants because of other sources except these three are highly negligible.

So these are the major three sources of accidents by generally responsible for destructive phenomena in chemical plants.

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Therefore to model them let us try to understand few technologies in basics of fire and explosions fire is a rapid XO thermal oxidation of any ignited fuel this fuel fortunately can be either a solid or a liquid or even in a vaporous form the vapor and liquid fuel or of course easier to ignite compared to the solid ones when it catches fire it releases energy slowly there is no sudden release of energy in case of fire.

But however the unfortunate part is fire can also result in explosions are result from explosions on the other hand fire an expression or integrated or interconnected you cannot separate them whenever there is a fire it may result in an explosion or the explosion can be derived because of fire if you look at expression characteristics the expression is a rapid expansion of gases resulting in a rapidly moving pressure or a shockwave the expansion can either be from mechanical or chemical reactions of the inventory materials.

The explosion damage is caused by pressure wave or a shock wave the explosion continuity to fire releases energy rapidly and it can result from fire so as I said fire and explosion are interrelated this process cannot be explicitly separated however fire releases energy slowly whereas expression releases energy rapidly.

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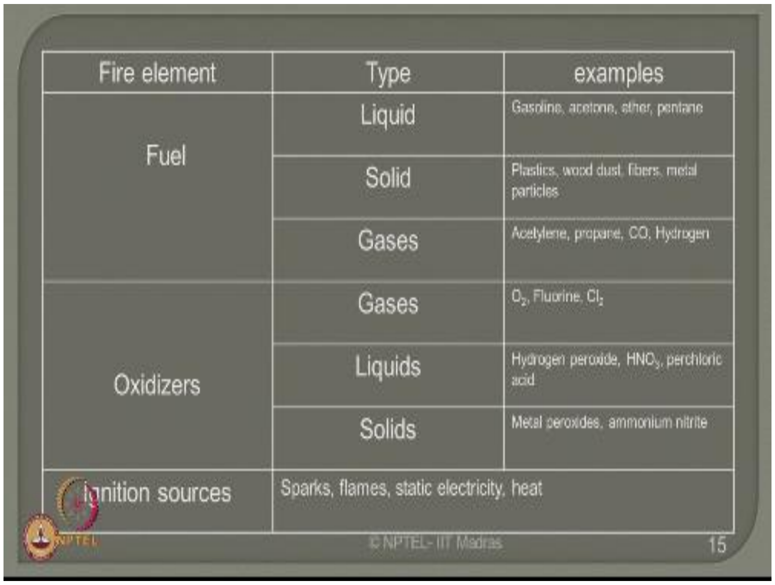

Fire element	Type	examples
Fuel	Liquid	Gasoline, acetone, ether, pentane
	Solid	Plastics, wood dust, fibers, metal particles
	Gases	Acetylene, propane, CO, Hydrogen
Oxidizers	Gases	O_2, Fluorine, Cl_2
	Liquids	Hydrogen peroxide, HNO_3, perchloric acid
	Solids	Metal peroxides, ammonium nitrite
Ignition sources	Sparks, flames, static electricity, heat	

Let us quickly see from this table what are the different elements that can cause fire what are the types of these elements which can result in fire and let us see quickly some of the examples on this list if you look at the fire element fuel as one of the fire element it can be either liquid it can be solid but can be gaseous state for liquid the examples can be gasoline, acetone, ether pentane, etc…

Solids which can catch fire as a fuel is plastics wooden dust fibrous material and metal particles whereas the gaseous States acetylene, propane, carbon monoxide, hydrocarbons etc… Can be fuel which can cause fire if you look at oxidizers which are also available in three different states as solid, liquid and gas gaseous can be oxygen, fluorine, and chlorine liquids can have examples as hydrogen peroxide nitric acid perchloric acid etc…

And of course solids can be metal peroxide and ammonium nitrate which are classically few examples which are very common in hydrocarbon industries the third important element which is responsible for fire is the ignition source the source of ignition for causing fire can occur by a spark on the top side of the plant it can be flames it can leave in static electricity or it can be heat which can cause XO thermal reaction from the chemical inventories available on the plant.

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Now the essential question comes after understanding basic characteristics of fire and explosion how can we prevent the fire or an explosion accident now if we look at this triangle which is shown on the screen now this is famously known as fire triangle is fire triangle has got three arms one is the oxygen arm the other is a fuel alarm the third one is the ignition source hypnotically friends if any one of this arm is not present it will not result in fire.

But unfortunately if you remember and understand the offshore or a process plan cannot sustain a process industry without any one of these three arms because we need oxygen in a plenty for chemical reaction of course fuel is a participating element in any chemical process industry and of course how carefully you do equation sources as shown in the last slide cannot be completely avoided they can be inspected mitigated rectified and managed comfortably therefore a fire triangle which is hazards scenario in unique process industry will always exist live in industry because the arms of the triangle can never be forbidden for any specific practical reasons.

Therefore fire and expression accidents can be prevented hypothetical if you know the knowledge of the following you must clearly know the fire and explosion characteristics of the inventory material available in the plant the nature of fire and explosion process you should also know different procedures to reduce the fire and explosion hazards as I insisted if you look at this triangle if you are able to get rid of any one of the arm of the triangle fire and explosion can be prevented in the industry.

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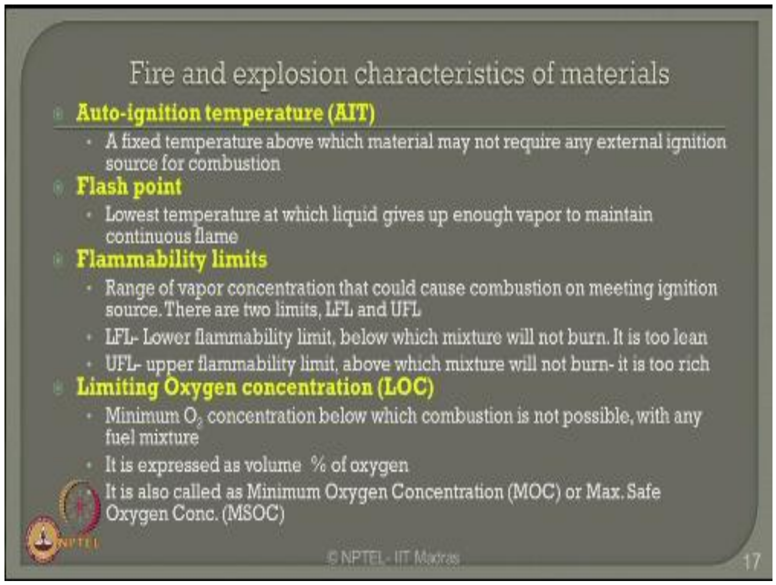

Therefore let us try to understand some basic characteristics of fire and explosion of the materials which can result from fire and explosion every material which can cause or result a fire and explosion you have something called auto-ignition temperature abbreviated as AIT in the literature is nothing but a fixed temperature above which material may not require any external ignition at all for combustion every material has a characteristic temperature which is an auto ignition the term itself makes you to understand he does not require any external ignition source at all.

Even in the absence of ignition source if the temperature in the process industry those higher than AIT of the inventory material stocked in the plant the material can catch fire the second important characteristic of flammable materials is called flash point it is the lowest temperature at which liquid gives up enough vapor to maintain a continuous flame please understand all these terminologies are related to operational temperature in a given plant where you have no control.

Because the temperature is a continuous changing process in a given system flashpoint is the lowest temperature at which the liquid will give up enough vapor which can keep the fire or the continuous flame there are something called flammability limits for any given material there are two limits called lower flammability limit and upper flammability limit abbreviated as LFL and UFL respectively LFL is a limit below which the mixture will not burn because the mixture will you come too lean UFL is a limit upper limit above which the mixture will not burn because the mixture will be too rich.

So there is a range of vapor concentration which could result in combustion of any material and this range is given between the lower flammability and upper flammability limits of any given material as I said in the fire triangle one of the important arm is the present of oxygen so there is something called limiting oxygen concentration which is called LOC in the literature this is the minimum oxygen concentration below which the combustion is not possible with any fuel mixture.

So on the other hand hypothetically friends if your temperature is not reaching above AIT and if you are controlling the external ignition source and if you are able to maintain the oxygen concentration below the limiting oxygen concentration value of any flammable material obviously you can design the system which will not have any fire accident at all but unfortunately chemical process is a continuous scheme the temperature variation is not under the control in the process.

Therefore there is always a possibility that AIT may be reached in a given process scheme or oxygen concentration certainly will be above the LOC which can initiate fire because the material will not catch fire if it is below the minimum oxygen concentration in the literature the LOC is expressed generally as percentage of oxygen it is sometimes called MOC there is minimum oxygen concentration or MSOC which is maximum safe oxygen concentration.

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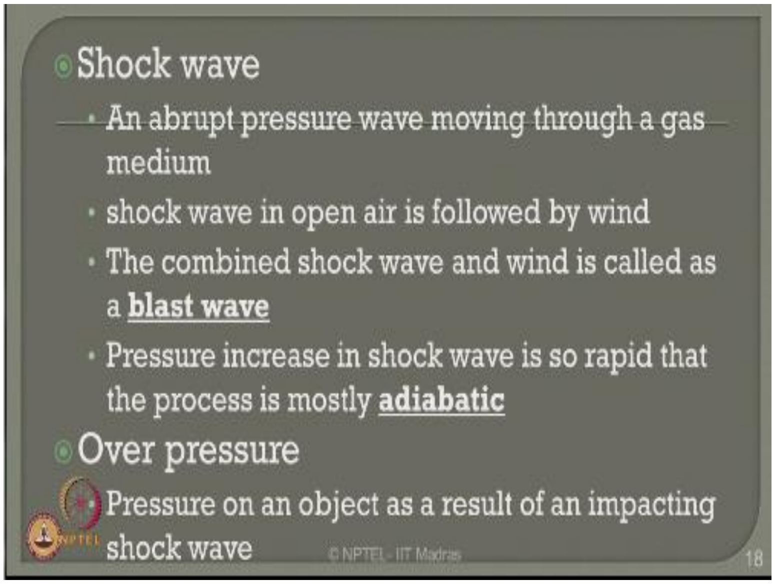

Having said this let us quickly see what would be the consequence of a shock wave and the blast wave in terms of this characteristics shock wave is an abrupt pressure wave which moves through a gas medium shock wave in open air is generally followed by wind the combined shock wave in wind is called as a blast wave the pressure increase in shock wave is so rapid that the process is mostly adiabatic it may result in something called the overpressure. Over pressure is a pressure on an object as a result of an impacting shock wave.

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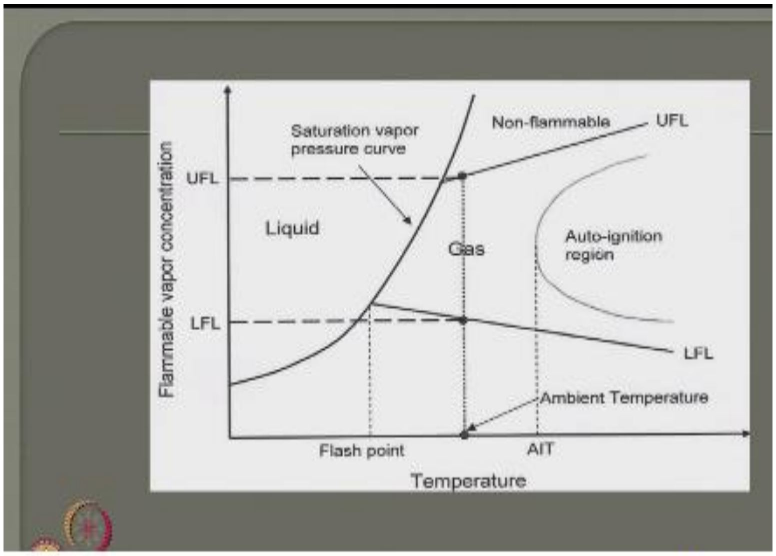

Let us quickly see this particular figure which is shown in the slide the figure plots the variation of temperature verses flammable concentration and there are two limits mark in the y axis which is lower flammability and upper flammability limits within which or between which the liquid or the fuel remains flammable beyond which and below which the fuel is not flammable that is why we are marked as non flammable beyond this region.

However for increasing temperature the flammable limits keeps on increasing it is very unfortunate at higher temperatures you will see that the range of flammability of the material is higher but however if you are able to maintain the temperature within auto ignition then in that case the flammable region can be limited only to the zone because beyond which auto ignition will not be present therefore the fuel will not catch fire.

So this figure shows you the range of flammability of liquid and gases as I said the gas will be comparable be on a specific point which is called as the flashpoint.

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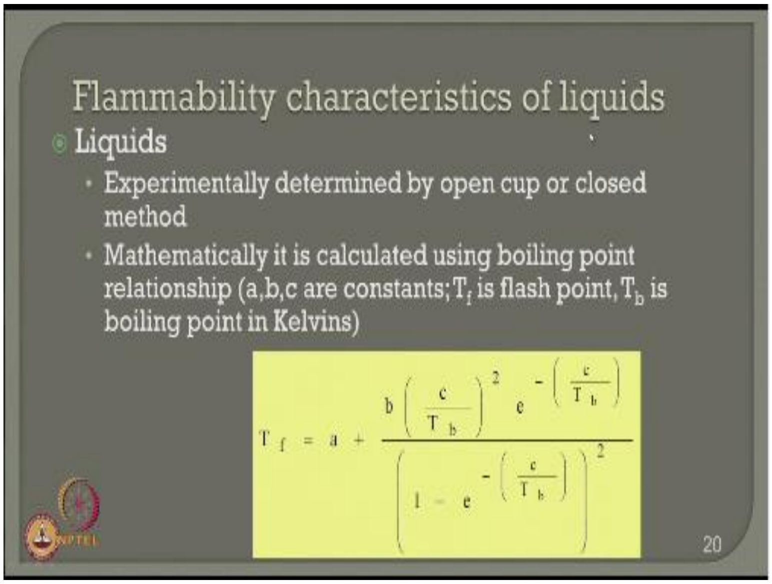

Now I want to obtain the flammability characters of given liquid the equation shown in the slide will help you to estimate the flammability of a given liquid provided the constants a b c etc… are known to me from the table let us see what are these constants liquids can be estimated for the flammability characteristics essentially the lower flammability and upper flammability and the flashpoint is in the equation mathematically it is calculated using boiling point relationship where a b and c are constants available in the literature chemical engineering handbook for a given mixture T_f is the flashpoint T_b is a boiling point both the values in Kelvin's.

Of course the constants are only a b c. a b and c this is an exponential position is a constant is e power exponential power of this value where as T_f is a flash point and T_b is a boiling point of the given liquid now for different kinds of liquids in hydrocarbon industry.

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Chemical group	a	b	c
Hydrocarbons	225.1	537.6	2217
Alcohols	230.8	390.5	1780
Amines	222.4	416.6	1900
Acids	323.2	600.1	2970
Ethers	275.9	700.0	2879
Sulfur	238.0	577.9	2297
Esters	260.5	449.2	2217
Halogens	262.1	414.0	2154
Aldehydes	264.5	293.0	1970

The table gives you approximately the abc constant values for hydrocarbons alcohols acids ethers, sulphur, halogen aldehydes you have the constants abc which has been estimated. Essentially from an open cup or a closed cup method so this table is available in standard chemical engineering handbook for different kinds of chemical groups for which these constants are readily available in the literature once theses constants are known you can easily compute.

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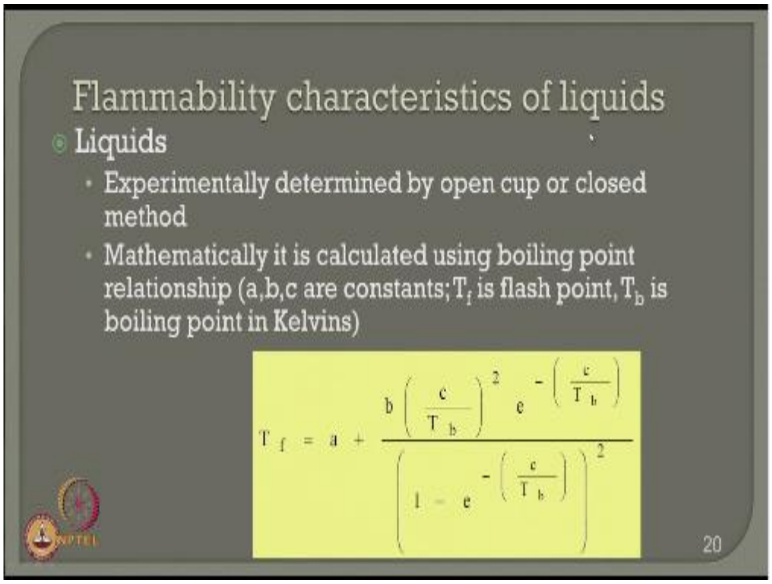

The flashpoint of the liquid even though experimentally this can be also computed directly by an open cup or a closed cup method.

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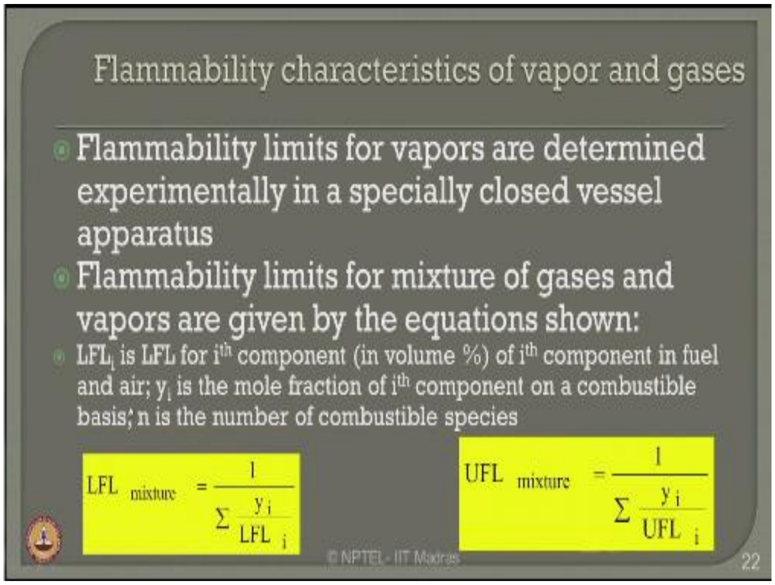

Once again the flashpoint the next important characteristic will be the flammability range so I must have the LFL and UFL values of the given mixture or a given vapor and gases flammability limits for vapor are determined experimentally in especially closed vessel apparatus flammability limits are mixture of gases and vapor are given by the equation shown below whereas if you know the flammability limits of heavy liquid or a mixture participating in the mixture then if you know the concentration of Y_i where Y_i is the mole fraction of ith component on a combustible basis and n is the summation with a number of combustible species available in the mixture LFL stands for lower flammability limit of the ith component whereas ith compound the fuel is present both in fuel as well as in air.

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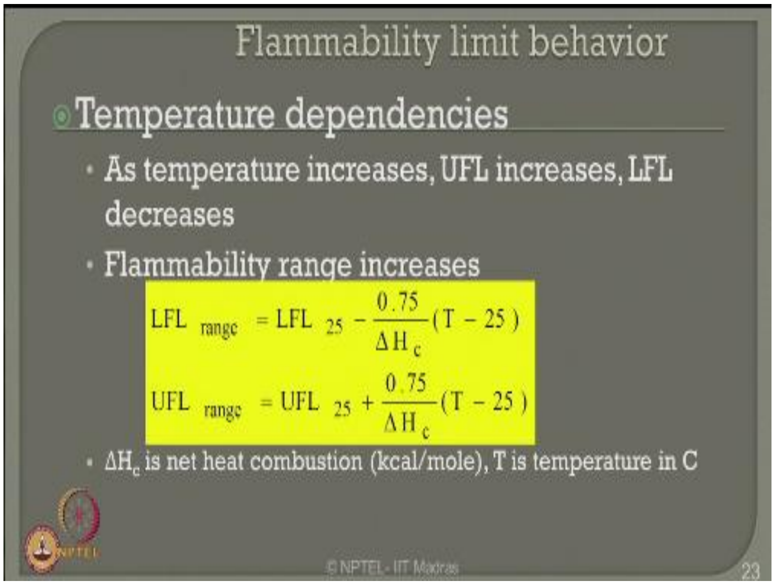

Can also work on the LFL and t UFL ranges directly from the flammability limit behavior let us quickly see what is the temperature dependency of the flammability limits as the temperature increases friends you saw in the last figure UFL and LFL decreases UFL increases therefore the range of the flammability keeps on broadening the flammability range therefore increases you can also work out this range from the equation shown in the slide now.

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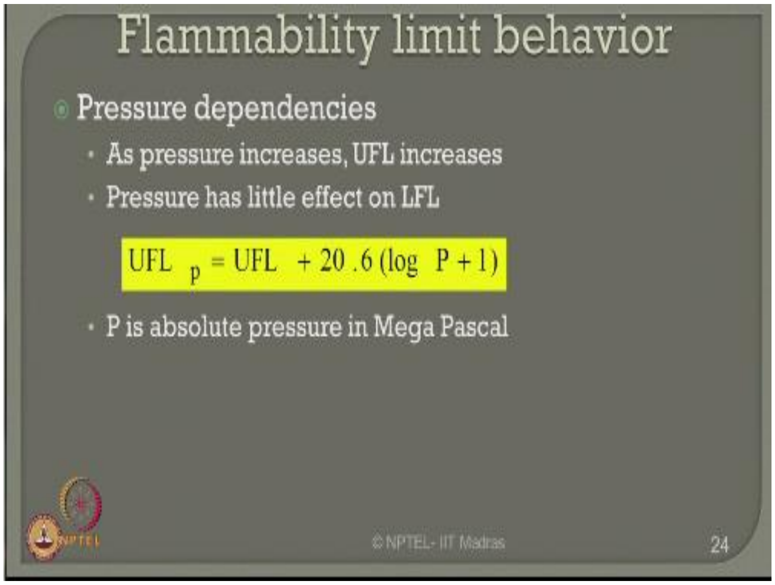

Flammability also depends on pressure as pressure increases the upper flammability increases however the pressure has very little effect on lower flammability this can also be directly obtained from the equation shown in the slide now where P is absolute pressure in mega Pascal.

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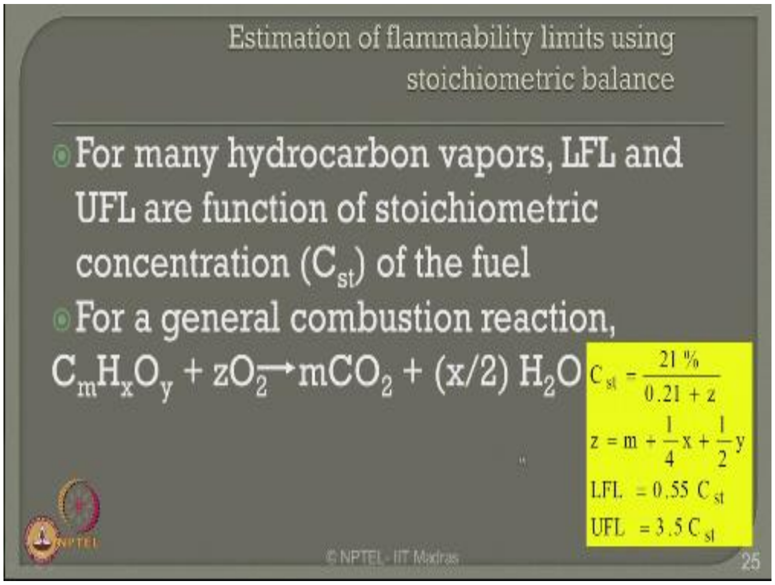

We can also estimate flammability limits using stoichiometric balance equation for many hydrocarbon vapors LFL and UFL or fortunately function of stoichiometric concentration CST of a given fuel CST or the stoichiometric concentration of any fuel can be obtained from the equation shown here by 21% .1+z where z is given by m+ ¼ of x+ ½ y where m x and y and z will be no discussed from the stoichiometric balance equation which will show you know once you have the CST value which is the stoichiometric concentration available from the equation one can compute the lower flammability and upper flammability of the given fuel using these two equations.

Now the question comes to understand what do you mean by z m x and y if you can have these values from a given stoichiometric balance equation which I am going to show you now one can easily work out the lower flammability and upper flammability mathematically however friends for every mixture or a given fuel which is ignitable you always have these limits available in the chemical inning handbook in open source domain.

So for general combustion reaction of an hydrocarbon m stands for the concentration of carbon x stands for the concentration of hydrogen and y stands for the oxygen concentration and of course z is the value which is for the oxygen concentration so if you maintain an stoichiometric combustion reaction and identify the values of m z x and y from the reaction substitute them here can usually find LFL and UFL of any given mixture or a fuel.

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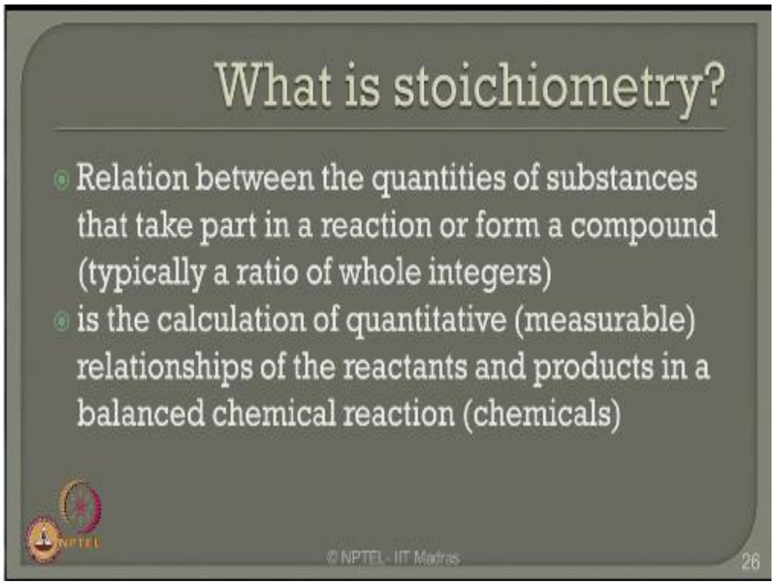

Now a point comes to understand what to stoichiometric, stoichiometric is actually relation between the quantities of substances that take part in a reaction or to form a compound typically is a ratio of whole integers here is the calculation of quantitative relationships of the reactants in a given reaction and the products in a balanced chemical reaction what we call stoichiometric equation.

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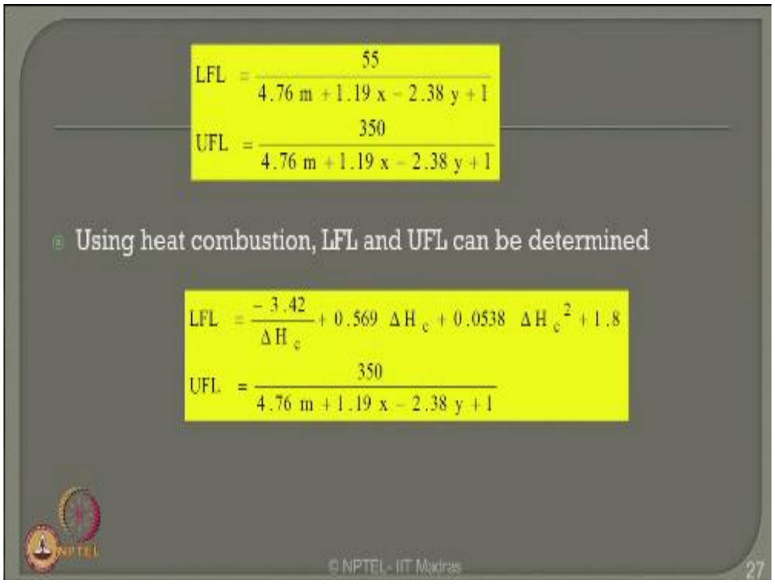

So LFL and UFL can also be obtained from the heat combustion equations as shown here where m x and y will be as same as what we explained in the last slide.

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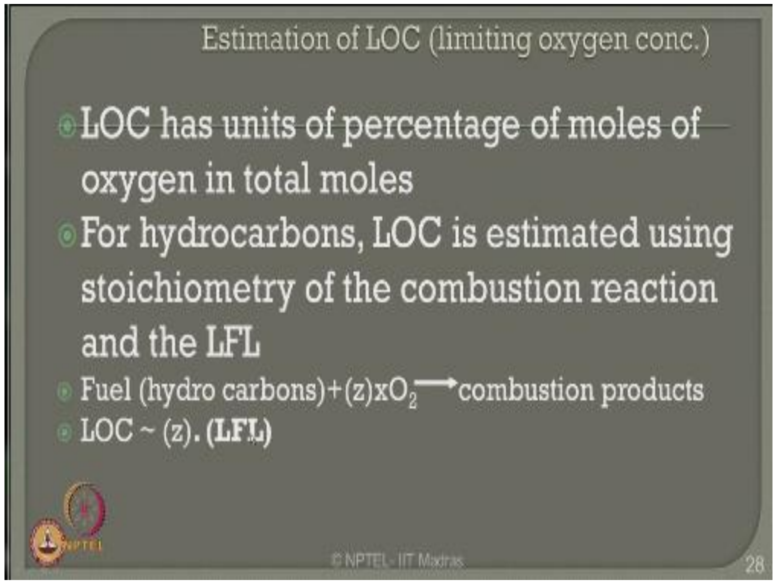

As I said it is very important to also know what is the limiting oxygen concentration because below distant oxygen concentration the fuel will not catch fire LOC has units of percentage of moles of oxygen in a total mole for hydrocarbons LOC is estimated using stoichiometric balance of a combustion reaction and the LFL hydrocarbons plus oxygen concentration gives me the combustion products loc is nothing but the oxygen concentration of the top LFL.

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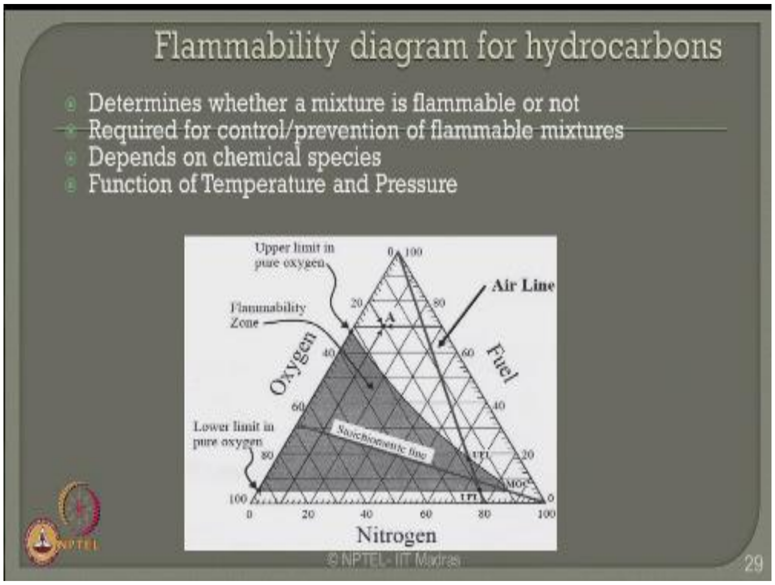

Once we know LOC the flammability limits and the flammability region and the flashpoint for a given fuel either from the chemical engineering handbook or from the mathematical equations shown to you in the previous slides then we talk about how to plot an flammability diagram for a hydrocarbon the diagram what you see in the slide is a typical example of a flammable diagram I will also show you a video at the end of the slide to draw the flammability diagram it is very important.

Let us try to understand the characteristics of the diagram this diagram essentially is a triangular in shape has got three arms nitrogen fuel and oxygen friends this diagram has got an order to plot if you look at the concentration of nitrogen, fuel and oxygen they all vary in an anti-clockwise manner for example the nitrogen concentration varies from zero to hundred where nitrogen is 100 fuel start at 0 then 0 to 100 where fuel is hundred oxygen starts at zero and goes from 0 to 100.

So nitrogen fuel and oxygen concentration is varying from 0 to100, 0 to 100 and 0 to 100 in an anti-clockwise manner out of these three as you said in the fire triangle similarly one arm is a few alarm other is oxygen arm our those is a nitrogen arm there is something called a line which indicates an airline which is joining the apex of oxygen arm with that of 79% nitrogen arm it is not 80 it is at 1 line below 80 so join the apex of oxygen with that of 79% of nitrogen and this line is what we call as air line.

Now the question is we should know for a given fuel how to mark the flammability zone which is hatched in the figure here, so let us take an example and understand how to mark the flammability zone for a given fuel because if you know the flammability zone for a given fuel if I am able to maintain the concentration of oxygen or the fuel or the nitrogen in a given scenario beyond the flammability region of the zone the fuel will not catch fire so flammability diagram is also used for effective control of fire accidents in process industries.

Flammability diagram whether a mixture is flammable or not on the other hand if the fuel concentration lies in the flammable region or the z of a given flammability diagram it is sure that the fuel will catch fire therefore flammability diagrams are required for controlling or preventing accidents of flammable mixtures of course it depends on chemical species it is a function of both temperature and pressure.

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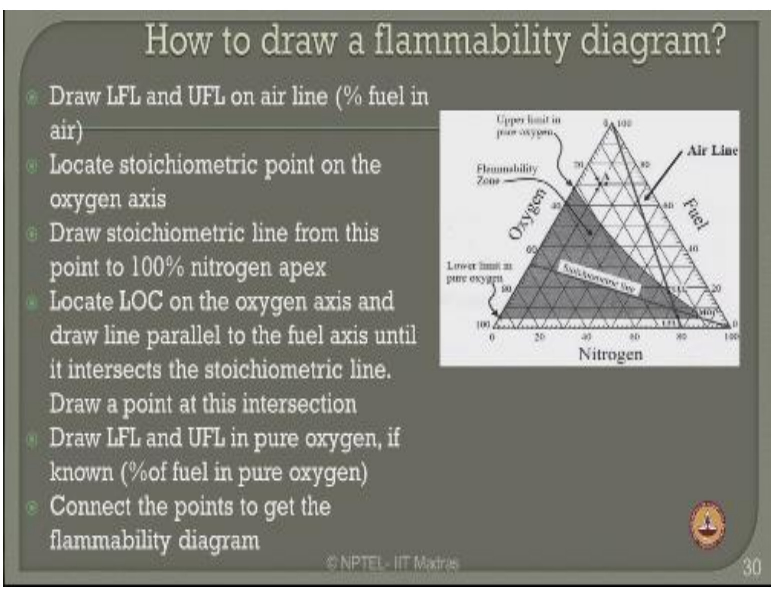

Now the question interesting comes how do I draw a flammability diagram to start with Flammability diagram is a triangular-shaped figure there is got three arms nitrogen, fuel and oxygen the concentration of them in every arm varies in a specific style 0 to 100, 0 to 100, 0 to 100 in an anti-clockwise manner for a given percentage fuel in air try to mark the lower flammability and upper flammability of fuel on the airline.

Now what is an air line, air line is a point joining the apex of oxygen to that of 79% on nitrogen on the airline mark the UFL and LFA values of the fuel percentage in air on the air line now locate the stoichiometric point because you know the stoichiometric point will be the concentration of oxygen available mark that to the apex of the nitrogen point which is 100 locate.

The stoichiometric point on the oxygen axis which is available for a given mixture from the chemical reaction or the combustible reaction draw the stoichiometric line from this point to one hundred percent nitrogen apex as you see this figure now locate the limiting oxygen concentration on the oxygen axis now for this example which is drawn in the figure here the LOC is available here and draw a line parallel to the fuel axis until the this intersects the stoichiometric line join the point of intersection.

So you mark the point of limiting oxygen concentration on the oxygen arm then draw a line parallel to the fuel arm wherever it mix it meets the stoichiometric line intersect the point and mark the region as a flammability region draw the LFL and the UFL in the pure oxygen if known then try to complete connect the points and draw a flammability diagram.

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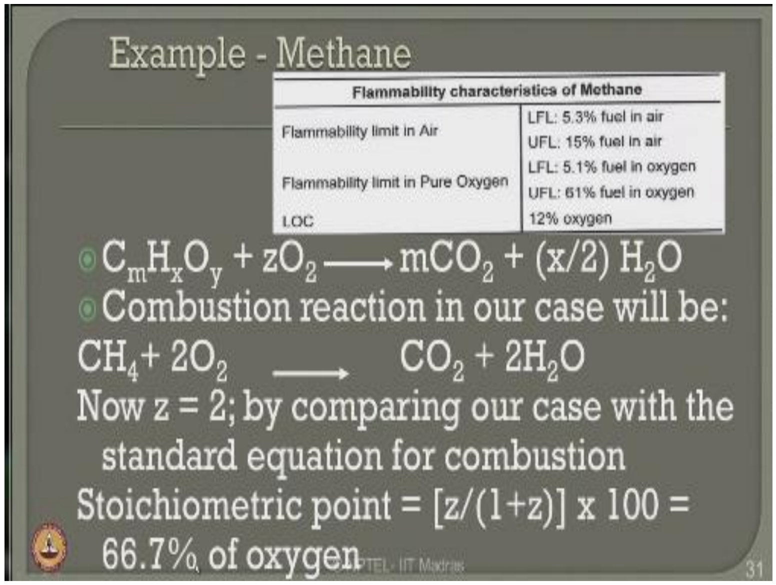

We will take an example of hydrocarbon problem which is methane which is ch4 now for methane the flammability characteristics are available in the literature as follows the flammability limits in air that is lower and upper is about 5.3 and 15 fuel in air whereas the flammability limits in pure oxygen is about 5.1 percent fuel in oxygen and 61 percent fuel in oxygen the limiting oxygen concentration below which methane will not catch fire is about 12% of oxygen.

On the other hand friends methane requires minimum 12 percent oxygen content in a given space to catch fire so we know that what would be the stoichiometric general equation which is given in the slide now I want to apply this equation for CH 4 which is combustible reaction in our case so methane mixes with oxygen gets me the product as seen here comparing this equation with that of the standard stoichiometric balance equation I must estimate the values of concentration of carbon, hydrogen, oxygen and z value from this figure.

So when you compact you will see that the z value is becoming to therefore the stoichiometric point can be given by this equation as z/ 1+ z 100 which is 66.7 percent of oxygen is a stoichiometric point of the given fuel so the stoichiometric point can also be experimentally established but in this case we have used an algorithm or calculation to find out the stoichiometric point by looking at the combustion reaction of methane and looking at a weight age of the oxygen concentration in the given process that will give me the stoichiometric point for the given fuel.

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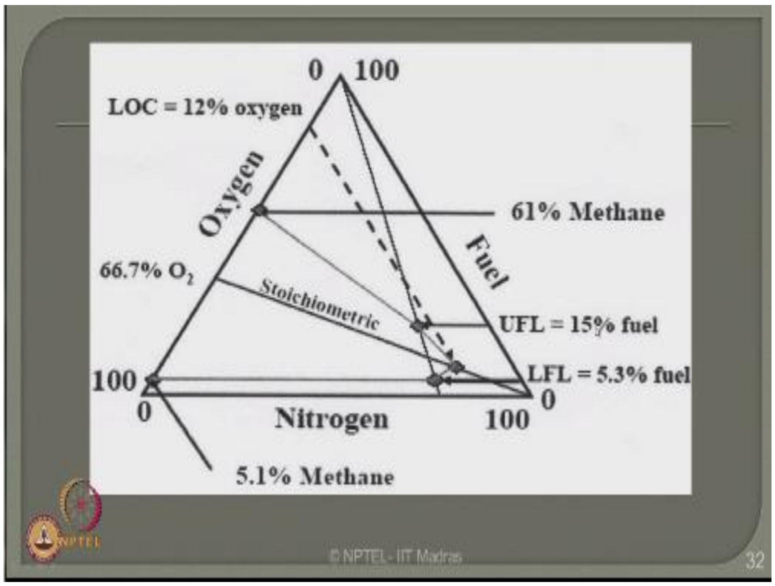

One similar stoichiometric point I draw the flammability diagram like nitrogen arm fuel arm and oxygen arm mark the airline which is apex or zero of oxygen is there are 79 percent of nitrogen which is called as an airline on the airline mark LFL and UFL of the fuel in air.

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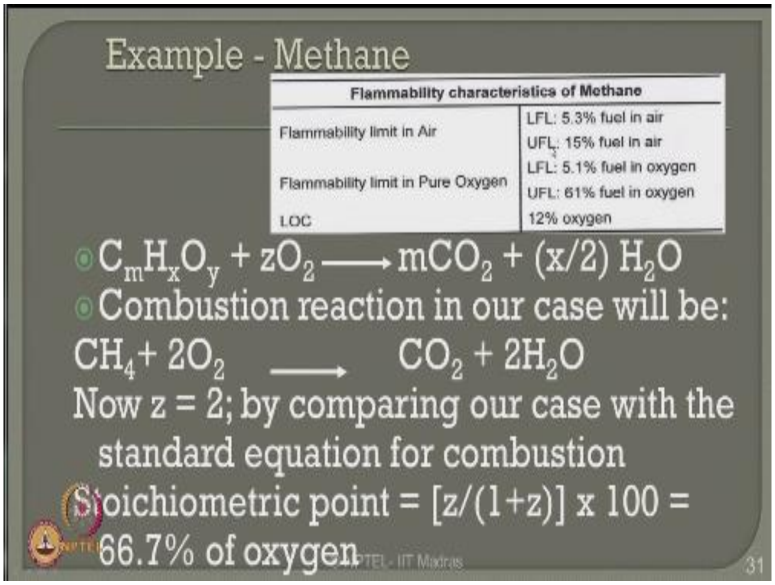

You please see here the LFL and UFL of the fuel in air is to be market on the airline.

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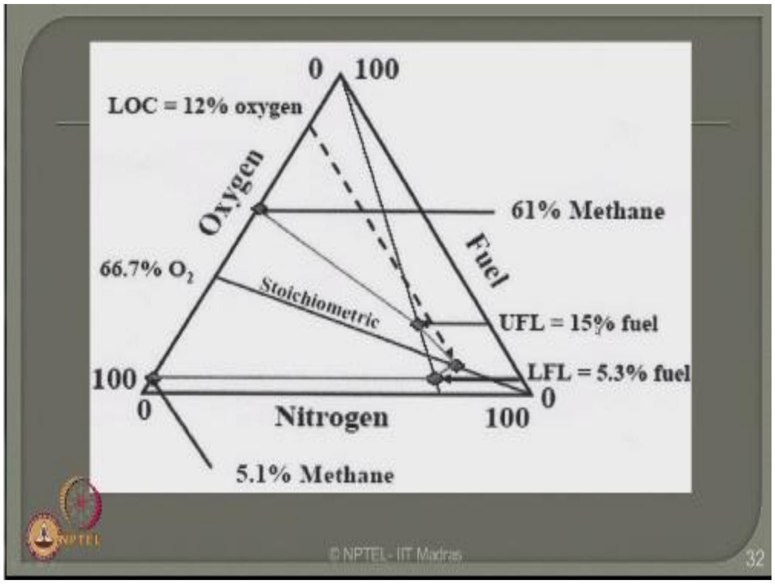

So 5.3 and 15 on the airline you just mark it here and extend it to the airline then you try to identify the stoichiometric point we just going to calculate a 66.7% you see from this equation here mark that join with 100 of nitrogen I get the stoichiometric line wherever the line intersects the limiting oxygen concentration now limiting oxygen concentration.

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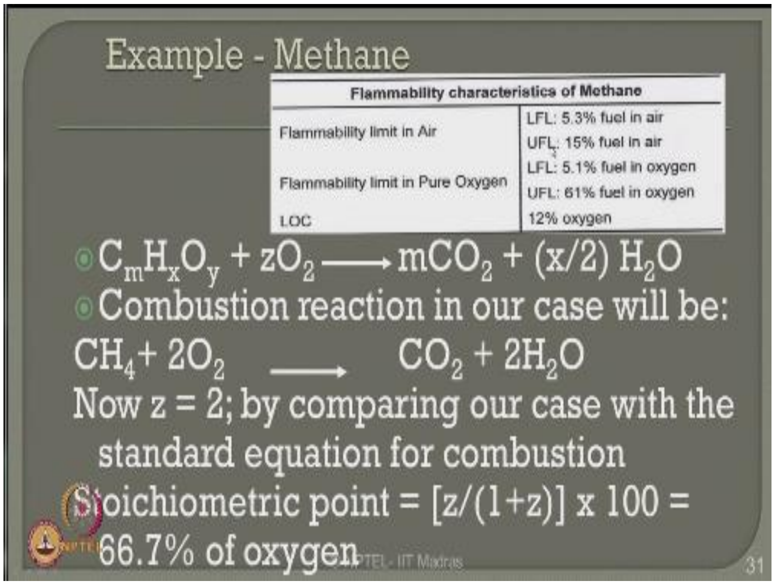

For this chemical or this hydrocarbon is twelve percent on the oxygen arm.

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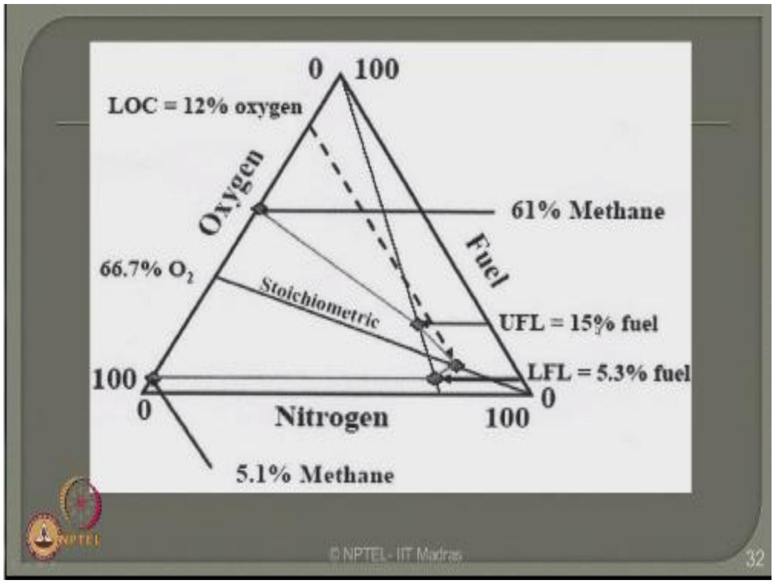

So mach twelve percent on the oxygen arm draw a line draw a line parallel to the fuel arm wherever this line and the stoichiometric line intersects mark the point and extend the LFL and UFL points now you get the values intersections as a b c d and e which is nothing but if 5.1 % methane and61% methane on the oxygen arm which are available here.

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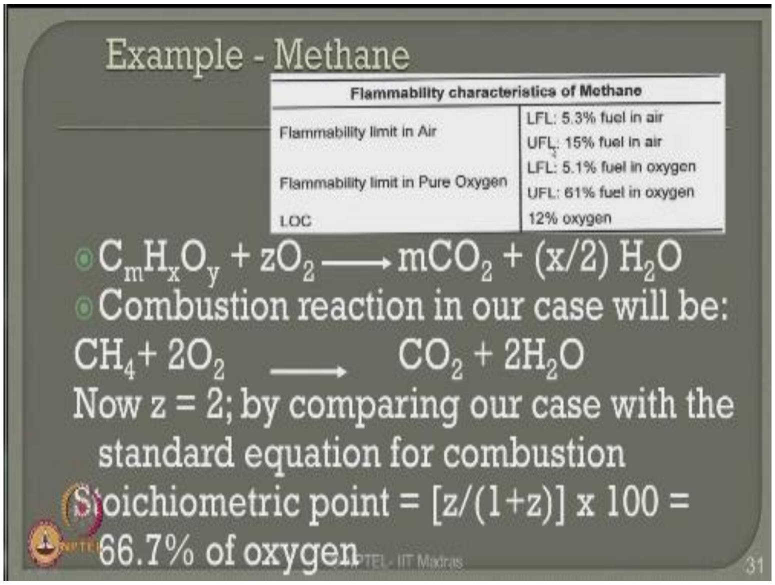

So I mark 5.1 percent.

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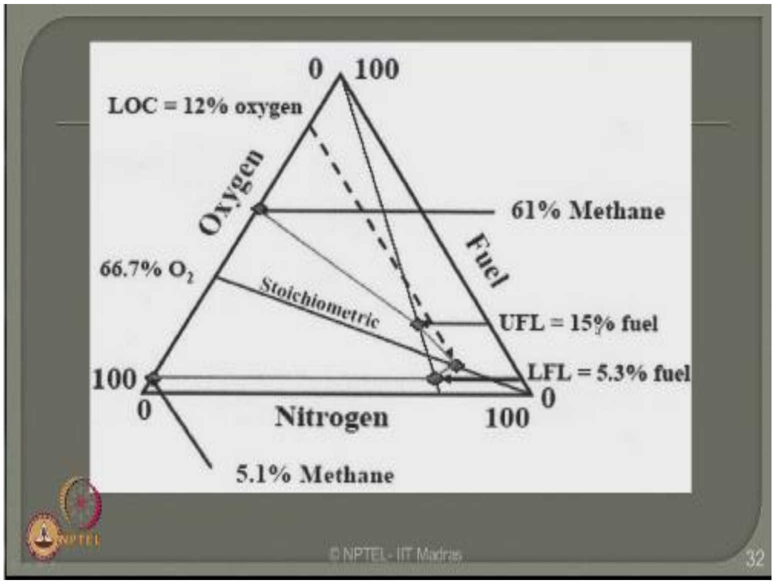

And 61 % respectively on the action arm I get these two points and preferably I get these two points intersected from the fuel arm on the airline of course this point is an intersection of the stoichiometric line with that of the airline I get now the boundary of the flammability region now if you hatch this, this becomes a flammability region.

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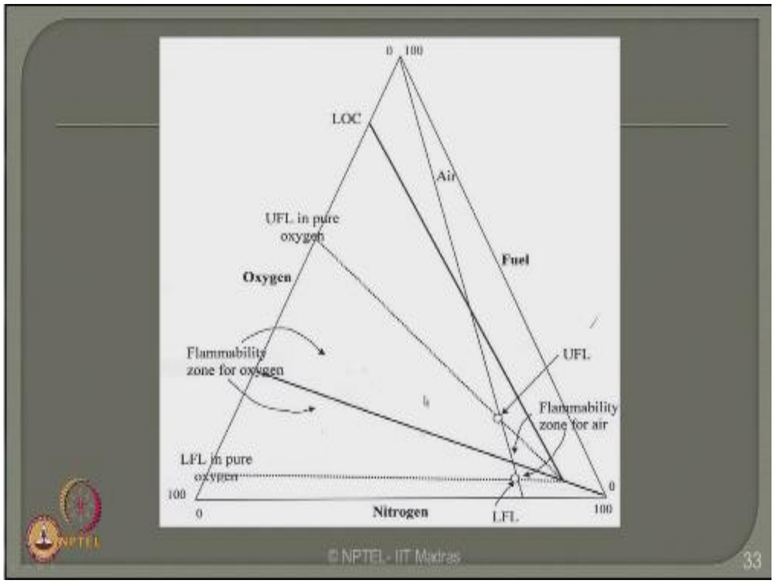

Which is again shown in the same manner so the flammability region in the specific example is what is shown between the dotted lines here this is the line which is limiting oxygen concentration which is marked on the oxygen arm and line drawn parallel to the fuel arm flammability diagram has got an order nitrogen fuel and oxygen market anti-clockwise 0 100, 0 100 and 0 100.

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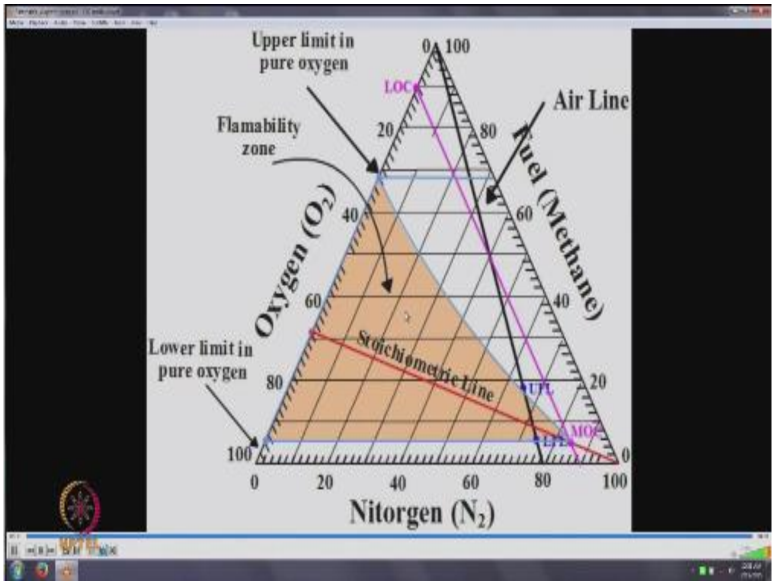

Now let us see a video quickly how to draw a flammability diagram the arm of the see is horizontal is a nitrogen arm 0 to 100 followed by which you draw the fuel arm which is methane 0 to 100 then the oxygen the prepare a grid select the apex of oxygen draw the airline then mark the stoichiometric point draw the stoichiometric line mark the UFL and LFL on the airline.

Then can also mark the LOC and draw a line parallel to the fuel arm and intersection of this with the stoichiometric will give you the MOC draw a line of LFL on the fuel arm and draw a line of UFL on the fuel arm mark the region of the flammability diagram. So this is the flammability zone which the fuel concentration will catch fire.

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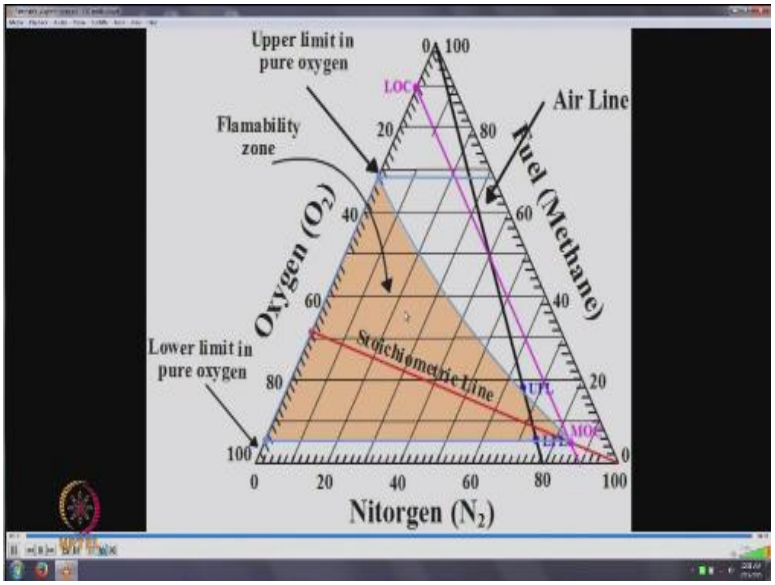

I play this once again nitrogen arm the fuel arm the oxygen arm is an order anti-clockwise airline seventy-nine percent nitrogen stoichiometric point taken from the reaction equation LFL UFL marked on the airline LOC marked on the oxygen arm draw a parallel to the fuel arm intersection of turkey will give MOC , LFL and UFL on the oxygen arm will me the boundaries and join this to get the flammability region hatch them to get the flammability region is what we call as a flammability diagram.

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Having understood this let us see what we mean by ignition energy this is a minimum energy which is an input required to initiate a combustion in a given reaction all flammable materials have something called minimum ignition energy which is available in the chemical engineering handbook which will show you an extract in the next slide of course the minimum ignition energy depends upon specific chemical or the mixture it is concentration temperature and operational pressure.

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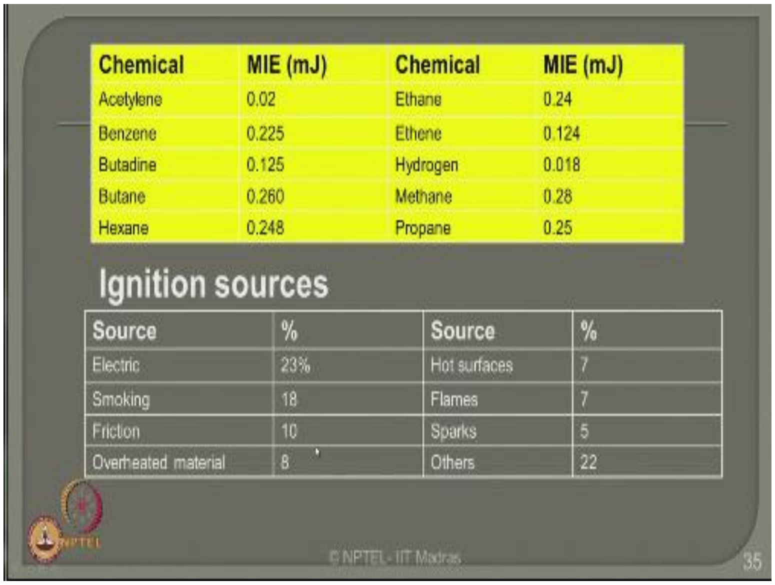

Chemical	MIE (mJ)	Chemical	MIE (mJ)
Acetylene	0.02	Ethane	0.24
Benzene	0.225	Ethene	0.124
Butadine	0.125	Hydrogen	0.018
Butane	0.260	Methane	0.28
Hexane	0.248	Propane	0.25

Ignition sources

Source	%	Source	%
Electric	23%	Hot surfaces	7
Smoking	18	Flames	7
Friction	10	Sparks	5
Overheated material	8	Others	22

The minimum ignition energy in mie mJ for different chemical is available which is extracted from a table let us quickly see what are the ignition sources in general these are the possible ignition sources in a process industry like electric smoking friction and overheated material if you look at the percentage of contribution of the sources to that of fire or expression electric short-circuiting is a very important major contributor for any extent followed with each smoking therefore if you avoid electric short circuiting by periodic inspection and proper maintenance and if you strictly here to the non-smoking regions in the process plants probably you will be able to avoid fire accidents more that about 50%

There are other sources which contribute also 25% which can arise from un foreseen incidences of course the sparks the flames the hot surface etc… they also contribute substantially to close to about twenty percent so put together if I can avoid electric short circuiting strictly adhere to non-smoking regions avoid overheating of the material and be careful in not allowing any flames or sparks in a given region I will be able to control the fire extent as close to about seventy percent in a given process industry.

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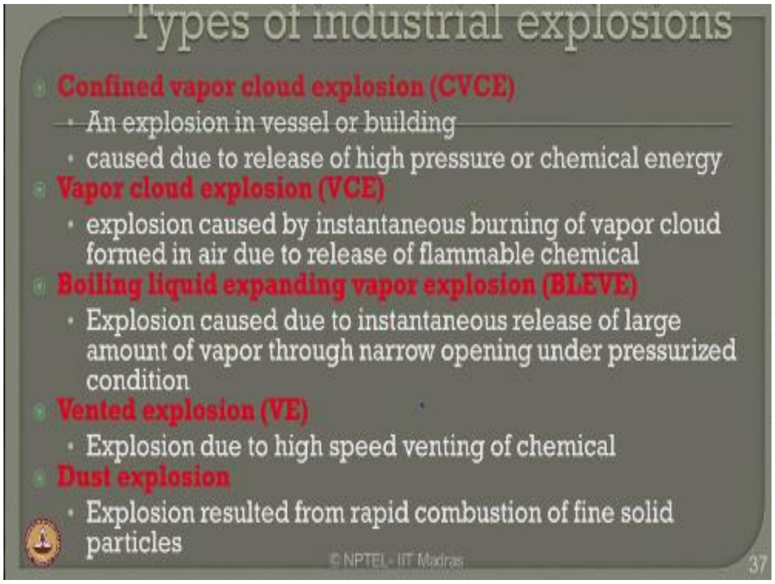

Expression of course we saw is a rapid release of energy causing development of pressure or a shock wave energy may be pressure energy or a chemical energy there are different types of industrial expression confined vapor cloud explosion an explosion which happens in a vessel or a given building it is caused due to release of high pressure or chemical energy vapor cloud explosion which is abbreviated as VCE is an expression costs by instantaneous burning a vapor cloud formed in air with the release of flammable chemical in the atmosphere boiling liquid expanding vapor explosion which is called as bloody explosion costs get instantaneous release of large amount of vapor through narrow opening under pressurized conditions vented explosion is an explosion resulting due to high speed venting of the chemical suddenly in the atmosphere thus the explosion results from rapid combustion of fine solid particles in the atmosphere.

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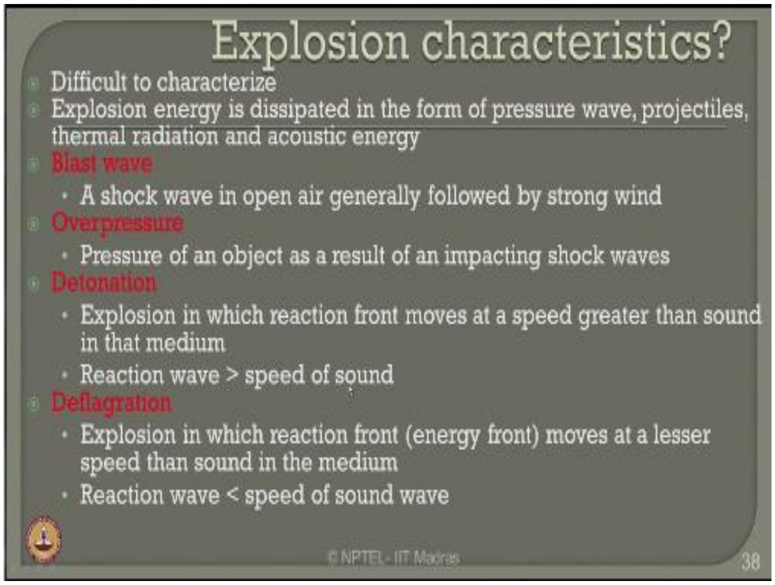

We have different expression characteristics which are very difficult to characterize expression energy is dissipated in the form of pressure wave projectiles thermal radiation and acoustic energy we have already seen a blast wave which is nothing but a shock wave and open air generally followed by a strong wind over pressure is a pressure of an object as a result of an impacting shockwave detonation is a form of explosion in which reaction front nodes at a speed greater than sound in that given medium the reaction wave is faster than speed of sound which is called as detonation alternatively there is a process called deflagration is an again explosion in which the reaction front moves at a lesser speed than sound in a given medium.

So the fundamental difference between the flavor and detonation is the reaction waves velocity in one case it is much higher than sound in the other case which much lower than sound.

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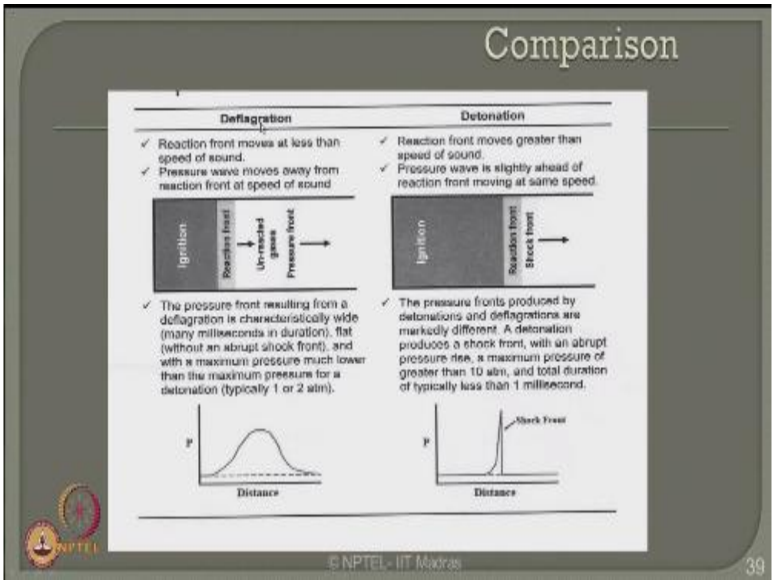

Let us quickly compare these two deflagration and detention both are explore explosions in deflation reaction front moves at lesser speed than sound wherein detonation it moves faster than sound the pressure wave moves away from the reaction front and the speed of sound whereas in this case the pressure is lightly ahead of reaction front moving on the speed you can see here the reaction front and the pressure front.

Whereas in this case the reaction friend and the shock front is in the product direction if you look at the defloration since the velocity is lesser than sound it creates a damage for a larger distance whereas the shock front of detonation is an impact wave which causes expression for a very short distance but a very high amplitude so in this case the amplitude may become comparable but the damage cost the declaration is much larger compared to the top detonation however the influence of expression on the given structure or material will be more severe in catastrophic if it is detonated compared to the top if it is deflagrated.

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Fiends in this lecture we discussed to understand how flammable diagrams can be plotted what are different essential characteristics of material which can cause fire what is a fire triangle how flammability diagram can be intelligently intercepted to avoid fire accidents in oil and gas industries thank you very much you.

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