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NPTEL ONLINE CERTIFICATION COURSE

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

Module 2:
Accident modeling, Risk assessment & Management
Lecture 8: Exposure models and design methods

Dear friends welcome to the eighth lecture on exposure models and design methods and the module of accident modeling, risk assessment and management in HSE course at NPTEL IIT Madras.

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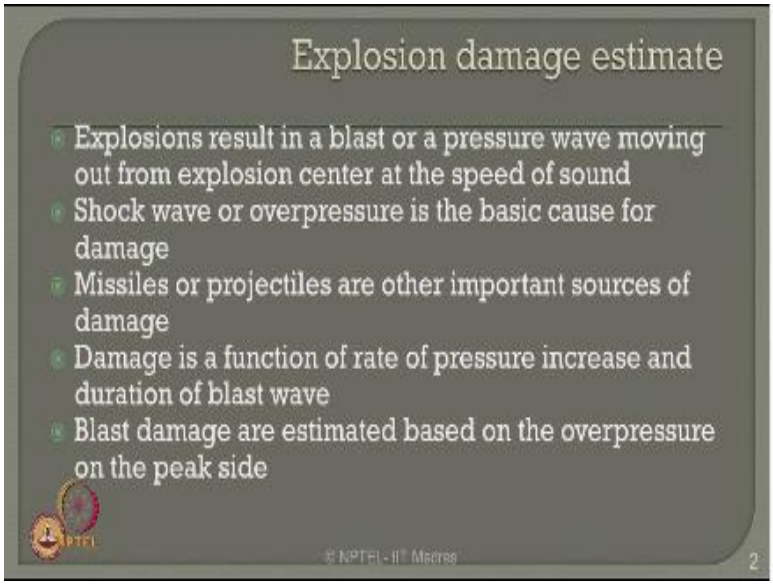

Before we look into the exposure models and design methods let us try to quickly recollect the different damage estimate for explosion. Explosions result in a blast or a pressure wave moving out from explosion center and the velocity of this motion will be approximately equal to that are speed of sound. Shock waves or over pressure is the basic cause for damages caused by

explosion. Missiles or projectiles are other important source of damage which are caused by explosion.

Damage of course a rate of function of rate of pressure increase and duration of the blast wave. Blast damage are estimated based on the overpressure on the peak side of the explosion damage.

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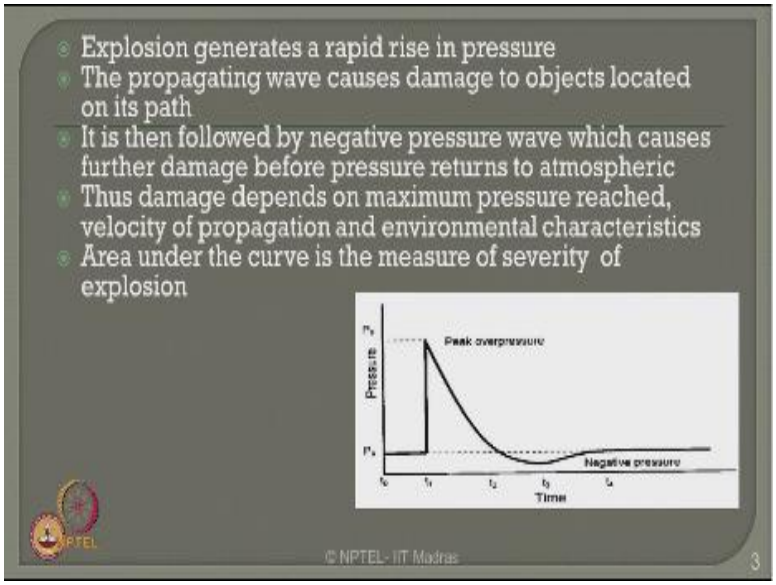

Look at the curve presented in the slide now, explosion actually release generates a rapid rise in pressure. So from the atmospheric the pressure rises to what we call as P_0 which is called peak over pressure in an instantaneous time from t_0 to t_1 subsequently after P_0 is reached the pressure drops down and it goes to section pressure we lay atmospheric before it comes to the atmospheric pressure. So the damage caused by the explosion is area under this curve.

The propagating wave causes damage to objects located on its path. It is then followed by a negative pressure wave which causes further damage before the pressure wave returns to atmospheric. Therefore the damage depends on the maximum pressure reached which is P_0 velocity of propagation and environmental characteristics. And therefore, it is very simple for us

to realize that area under this curve of P verses time will give me the measure of severity that arises from an explosion.

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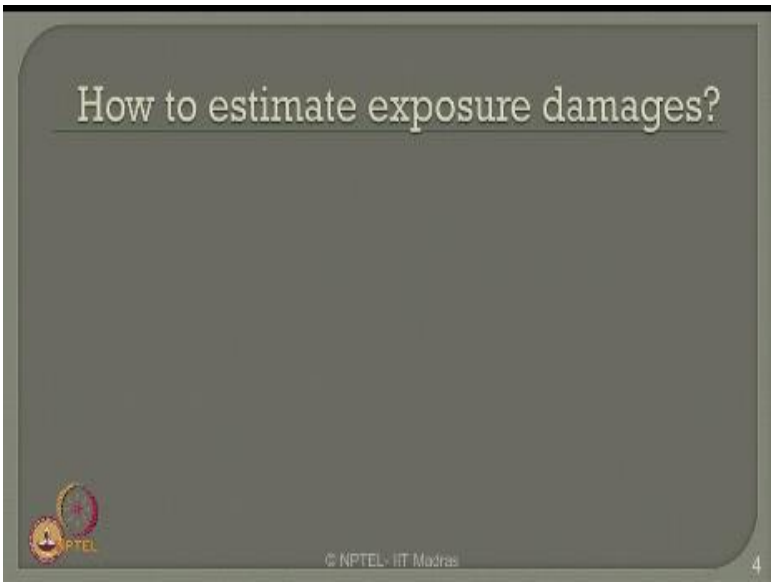

Now a question comes to estimate exposure damages?

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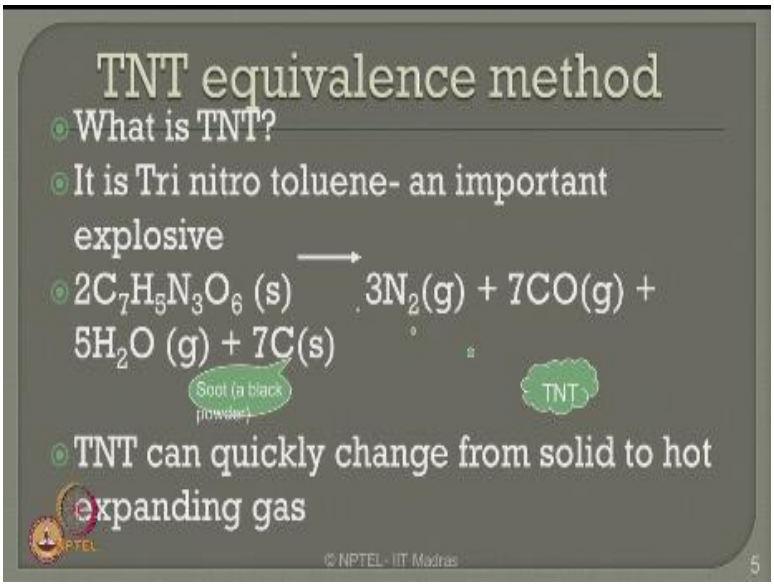

There are many methods available in the literature out of which, one of the most popular method is call TNT equivalence method. Let us quickly understand what is TNT then how to find equivalence from TNT to estimate the damage arise from different exposure models. What is TNT? TNT is Tri nitro toluene an important explosive which is got the chemical composition as shown in the slide now. The chemical composition has got components of the component shown in the figure now whereas the black powder which is the residual result from TNT is otherwise called as soot in the literature.

So this is the chemical composition of a TNT and this is a black powder results from TNT. TNT has got a very interesting characteristic it can quickly change from solid to hot expanding gases.

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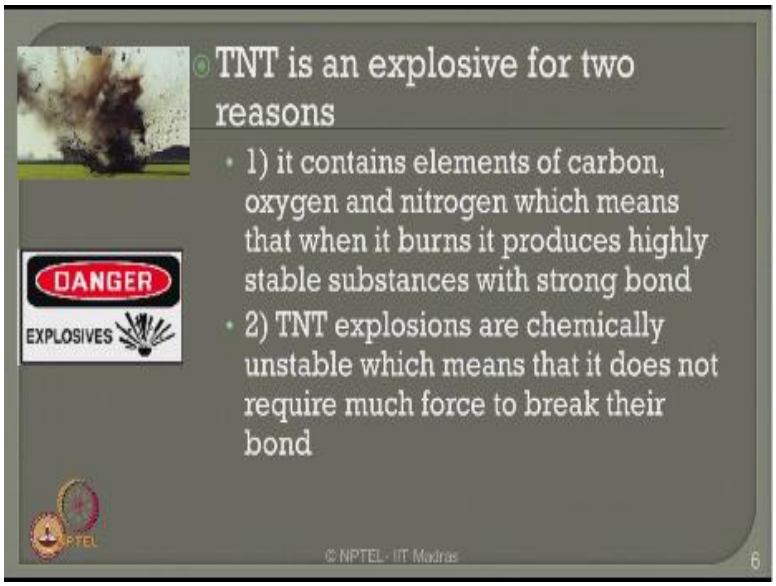

TNT is an explosive fundamentally for two reasons, one it contains elements of carbon, oxygen and nitrogen which means that when it burns it produces highly stable substances with strong bond with each other. TNT explosions are chemically unstable which means that it does not require mush force to break their bond.

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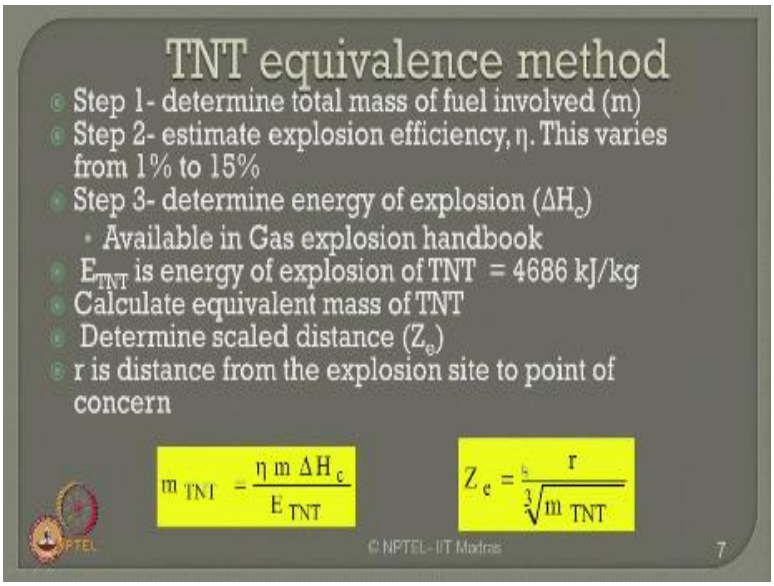

Now we are interesting looking at a mass equivalence of TNT which can be converted to an equivalent damage caused by the explosion. So step number 1, try to determine the total mass of fuel involved, so in this equation m denotes the total mass any explosive here which is involved in causing a damage. Step number 2, estimate the explosion efficiency Δ this efficiency generally varies from 1% to 15% in the literature.

Step number 3, determine the energy of explosion ΔH_c. ΔH_c for every chemical which is explosive is available readily in the gas explosion handbook. Now we should also know the value E_{TNT} which is the energy of explosion of TNT which can be taken as 4686kJ/kg, so once we have all these values available I will get mass equivalent of TNT which is an equivalent mass as the tuff the mass participating in the explosion.

Once I get the TNT equivalent mass I substitute here to get Z_e where Z_e is call the scaled distance and r is the distance from the explosion site to the point of concern. So once I have the r value substitute in this equation I will get the scaled distance Z_e which can be computed from the equation on the right side.

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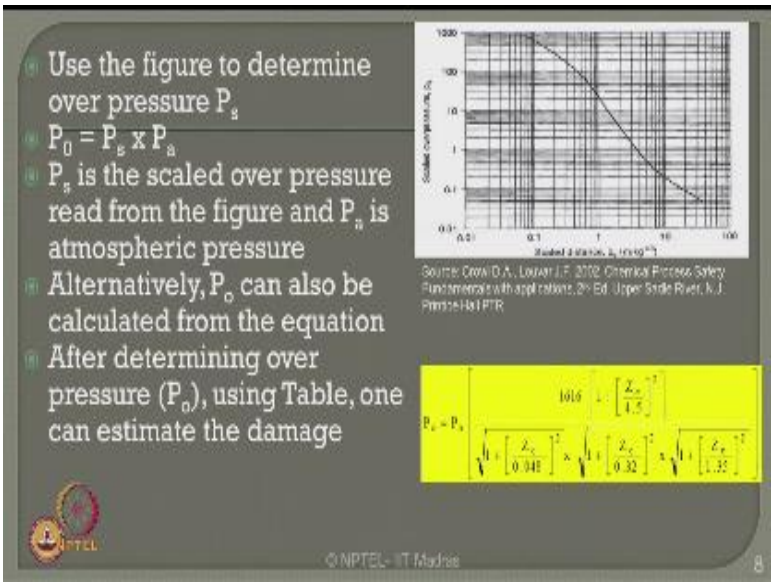

Once the scaled distance is lone to me looking at this curve I can estimate what we call scaled over pressure which is P_s. so one can use this figure readily to obtain P_s or alternatively one can also find the over pressure value from the equation given below. So if you know the over pressure value I can always find which is the product of P_s and P atmospheric. P_s is a scaled over pressure available from the chart which can be read from the figure directly and P of course is the atmospheric pressure.

Alternatively, P_0 can also be obtained from the equation given below where Z_e or the required to be substituted in this equation remaining all values are known to us. Therefore, after determining the over pressure using the table one can estimate the damage caused.

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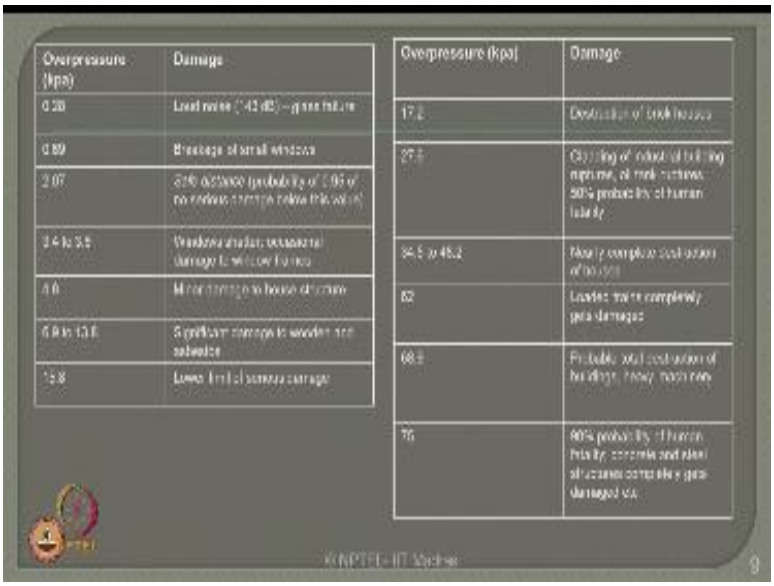

The table clearly shows here for a given value of over pressure the kilopascal, what could be equivalent damage which is available in the literature. So the equivalent over pressure in kilopascal varies from 0.28 to as high as 75 clearly causes relative damages as a simple loud noise which can result in breakage of glass which is caused which equivalent to 143 decibels. As highest 90% probability of human fatality can result when the over pressure damage can be as highest 75 kilopascal. So ladies and gentle men this is very important for us to first convert the given value of mass TNT equivalence to over pressure.

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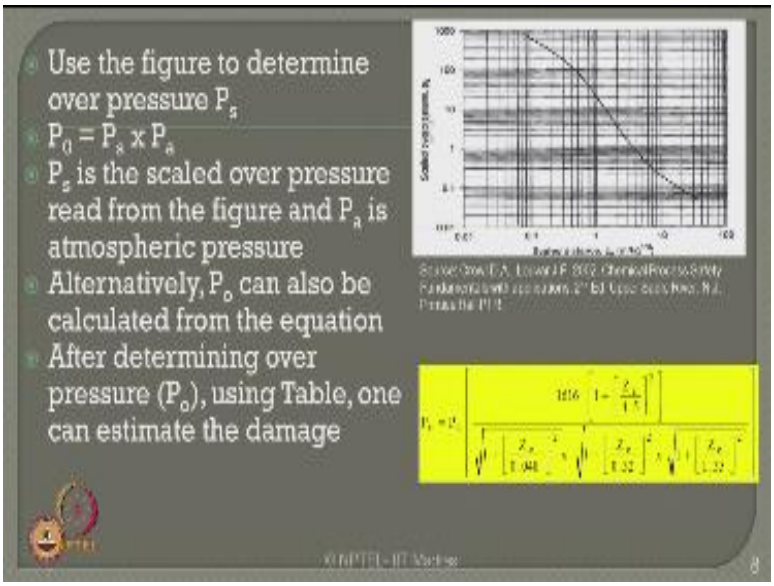

Which can be simply computed from this equation r from this equation for using this equation I must know P_s which can be taken directly from the chart for obtaining P_s from this chart I must know Z_e whereas Z_e is available from this equation directly.

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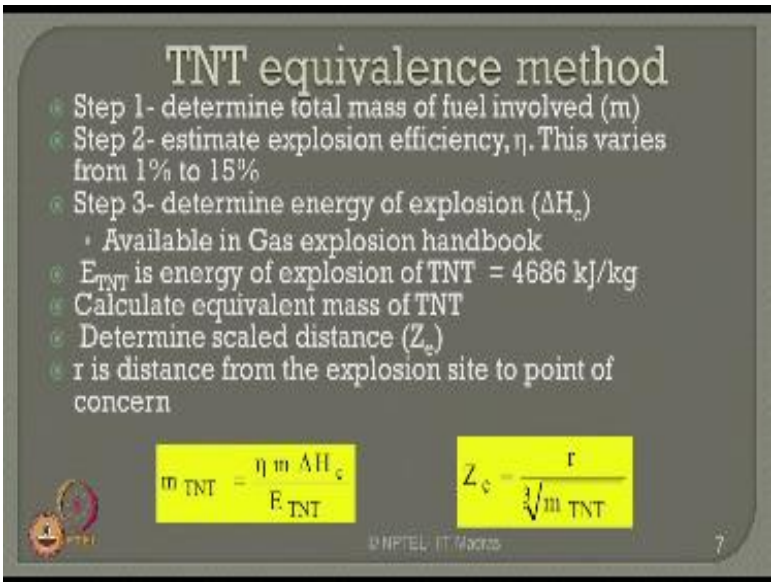

If you know mass TNT, so one of the most popular method available in the literature is mass equivalence of TNT if you know the mass participating of the explosive in the given damage. So Z_e is a local value which depends on what is the distance of your point of concern from the point of explosion site.

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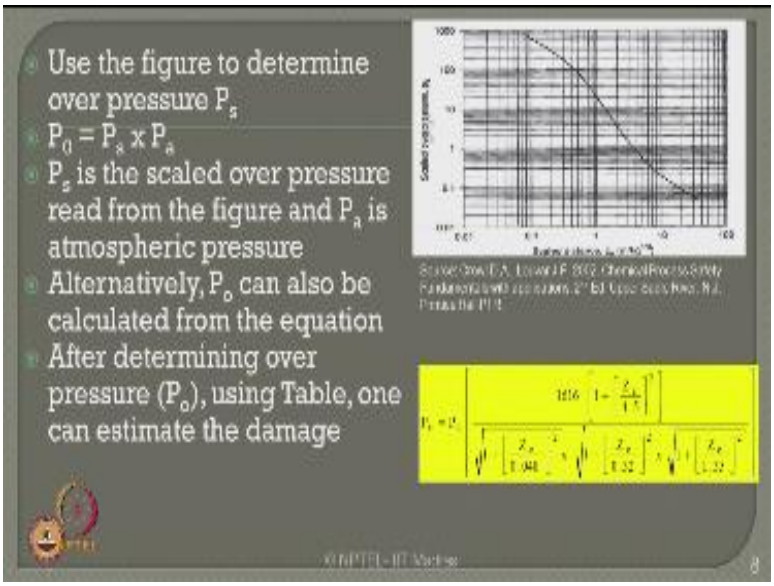

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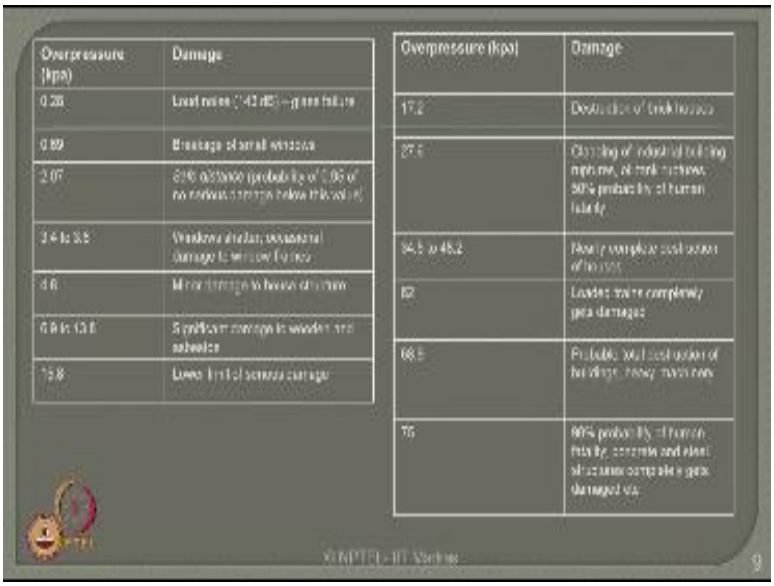

So once I have the over pressure value using this table I can equally find out the damage caused from the over pressure value caused by the explosion.

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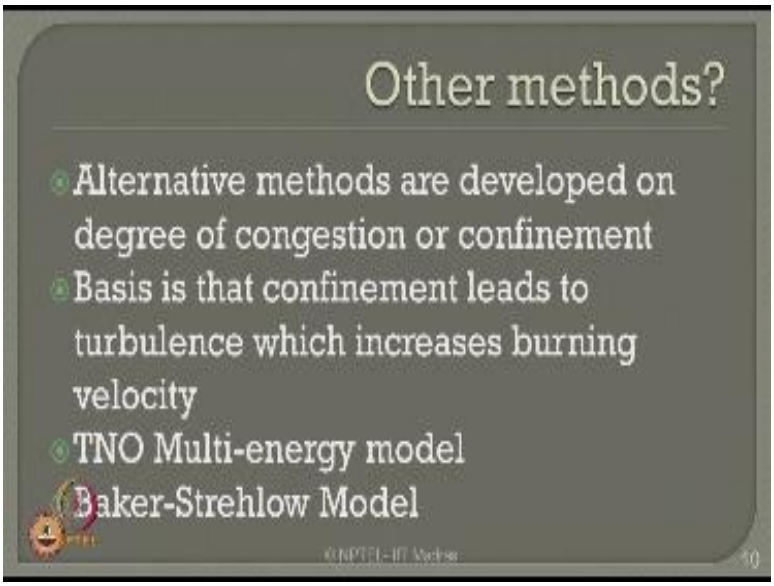

Other alternative methods are developed based on the degree of congestion or confinement. The basis is that confinement leads to turbulence which increases the burning velocity. TNO multi energy model is another alternative earlier the literature which can also help us to find out the damage arising from the exposures. Alternative method again available in literature is the Baker-Strehlow Model which can be used directly to estimate the damages from over pressure.

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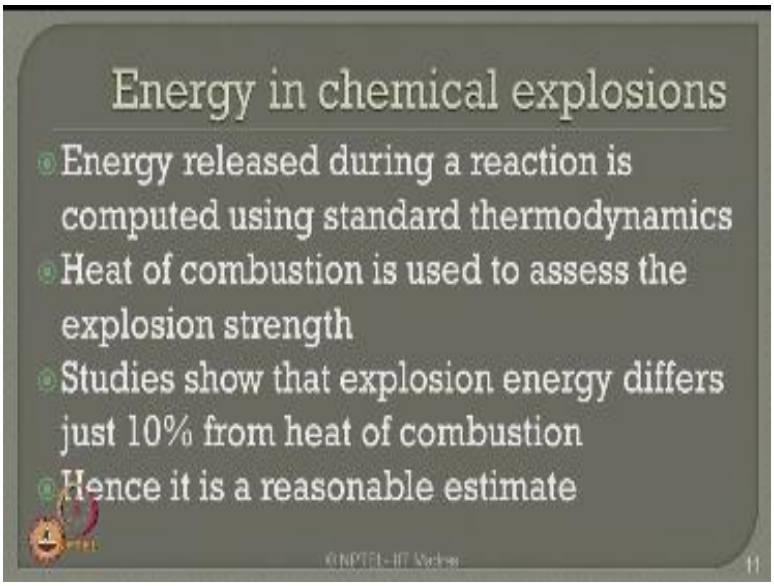

Friends we also know that energy in the explosions also a very important reason for creating damages especially we chemical explosions energy released during a reaction can be computed directly using standard thermodynamics law. Heat of combustion is used to assess the explosion strength. Studies show that the explosion energy differs only by a 10% from the heat of combustion. Therefore, the explosion energy can be directly use as an indicating measure so find out the damage caused by the chemical explosions.

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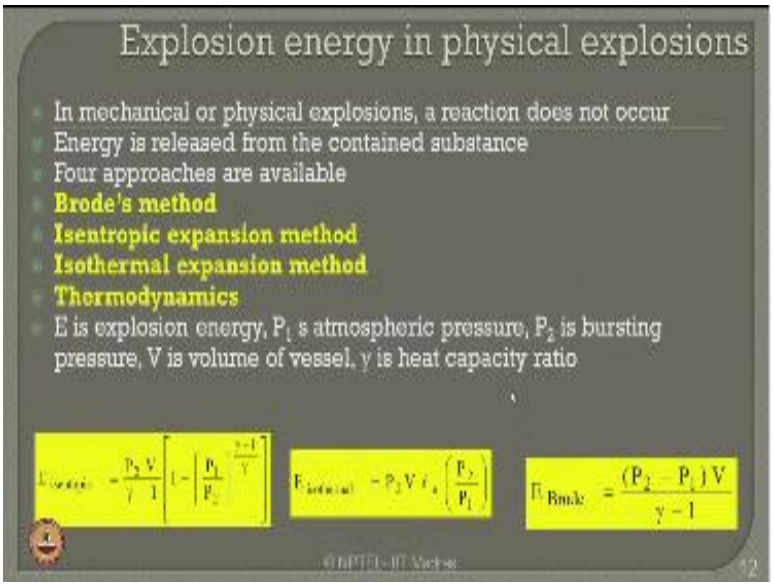

Explosion energy of course can also arise from physical explosions. In mechanical or physical explosions of course a reaction does not occur as that occurs in chemical reaction. Energy in this case is released directly from the contained substance. There are four approaches available in the literature namely Brode's method, Isentropic expansion method, Isothermal expansion method, thermodynamics law. We can use these corresponding equations for finding out the energy which is released because of the freezing expressions.

We using an isentropic method or an isothermal or Brodes' equation in this equation where E is exposure in energy P_1 available in the equation is atmospheric pressure and P_2 of course is the over bursting pressure which is resulting from the explosion, v is the volume of the vessel and u is the heat capacity ratio used in the equation.

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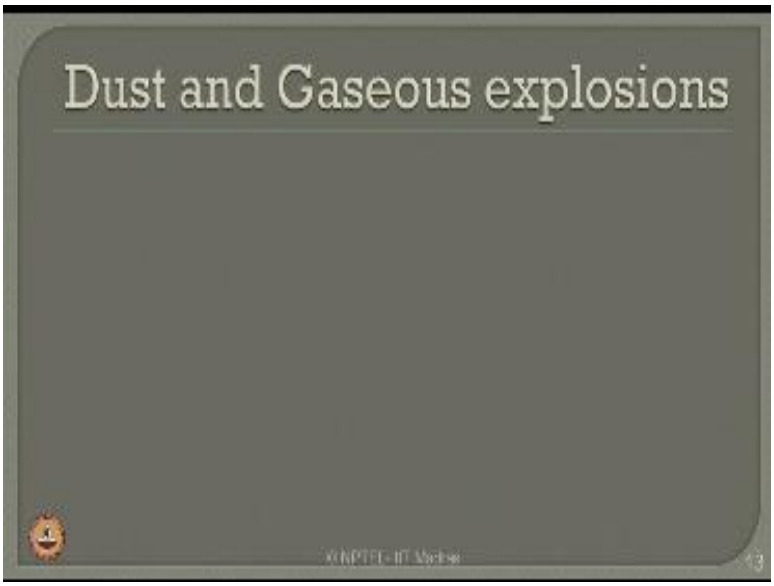

Alternatively we can also have a explosion resulting from dust and gas expansions.

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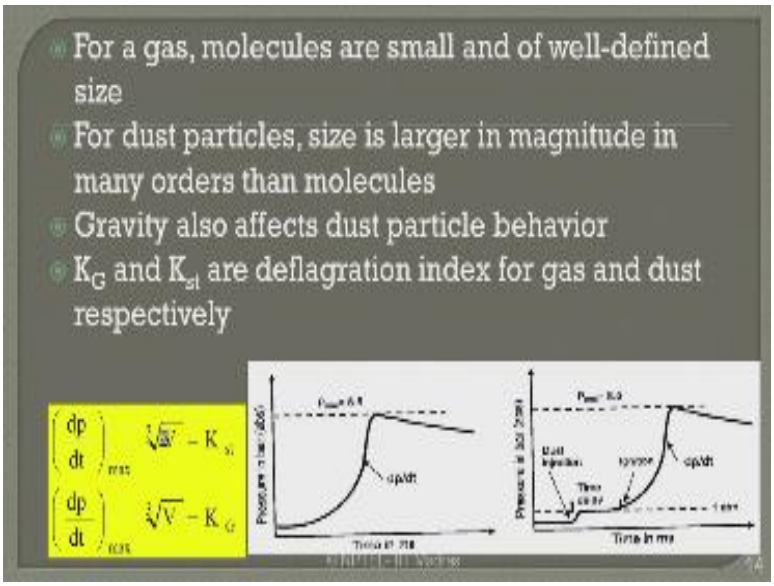

For a gas, molecules are small and are well defined in size. Alternatively for a dust particle size is larger in magnitude in many order compared to that of the gas molecules. Gravity also plays a very important affect because the dust particles behavior is significantly affected by the gravitational pressure. Equations available here for estimating the pressure in bar that arise from the pressure variant or the pressure differential as shown here is of a function of K_G and K_{st} where K_G is called deflagration index and K_{st} is called the deflagration index for the gas and dust respectively which can be given by this envier V is volume of expansion available in the container.

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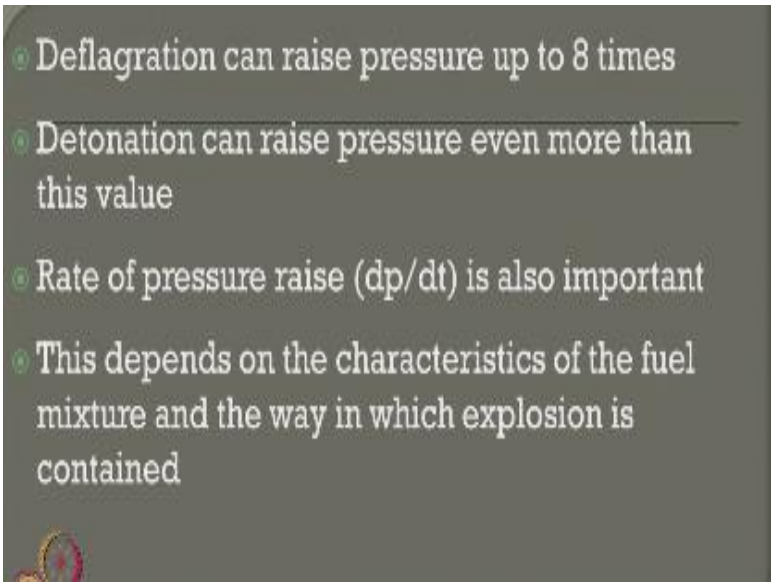

The deflagration can raise pressure up to 8 times whereas detonation can raise pressure even more than this value raise rate of pressure raise which is called dp/dt is also important factor which place role to estimate the damages cost by the energy release in case of explosions this of course depends on the characterizes of the fuel mixture and the way in which the explosion is contained.

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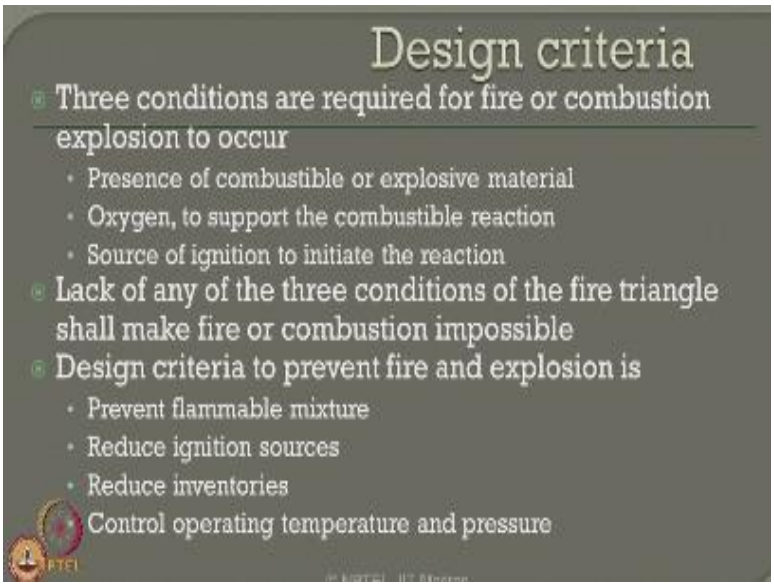

Now let us look at to some of the design criteria based on which we can contain or confine this explosions three conditions as we all understand are require for fire or combustion explosion presence of combustible material oxygen to support the combustible reaction and source of ignition to initiate reaction, lack of any one of the three conditions of the fire triangle shall make the fire or combustion impossible.

The design criteria therefore to prevent fire and explosion is that prevent flammable mixture reduce ignition sources reduce inventories which can cause ignition and control operating temperature and pressure.

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Let us now look at the list of preventive measures which can be adopted in industry for preventing fire and explosions following strategies are commonly used in the industry Inerting and purging which means reduce oxygen content or fuel concentration below a specific target value. You can also use fuel to diagram by which you can control three important elements of fire and explosion you can also use control in the static electrify as one of the strategy for preventing fire and explosion.

Reduce existence of ignition source in the given system provide a left ventilation which can be achieved by diluting the flammable mixture by adding more apt in the content use explosion proof equipment and instruments in the industry and of course use sprinkler systems to control if fire or explosion occurred.

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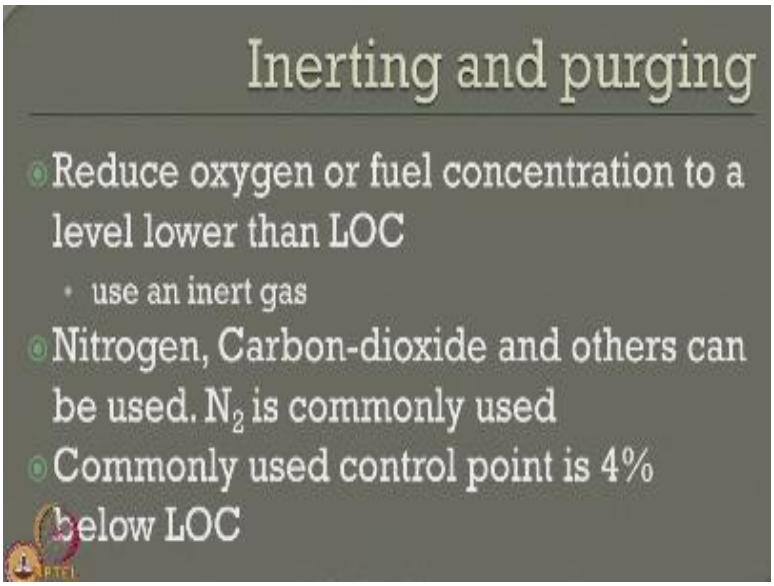

Let us look in to the design methods one by one in detail inerting and purging is a process value which you reduce oxygen content or fuel concentration to a level lower than the limiting oxygen concentration. To do this one general uses and inert gas nitrogen carbon-dioxide and others can be commonly used but however nitrogen is most popularly use for uniting operations commonly use control point is 4% below the limiting oxygen concentration.

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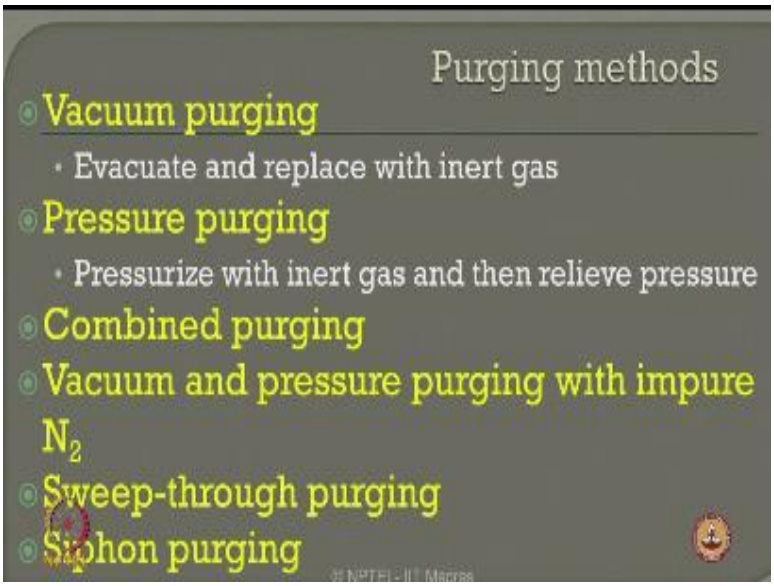

We look at the purging methods one can have different methods available in literature vacuum purging, pressure purging, combine purging, vacuum and pressure purging with improve nitrogen and sweep through purging incase of vacuum purging we evacuate and replace within it gas completely in case of pressure purging we pressurize within it gas and we will relieve the pressure from the given system. Alternatively we can also do what is called siphon purging.

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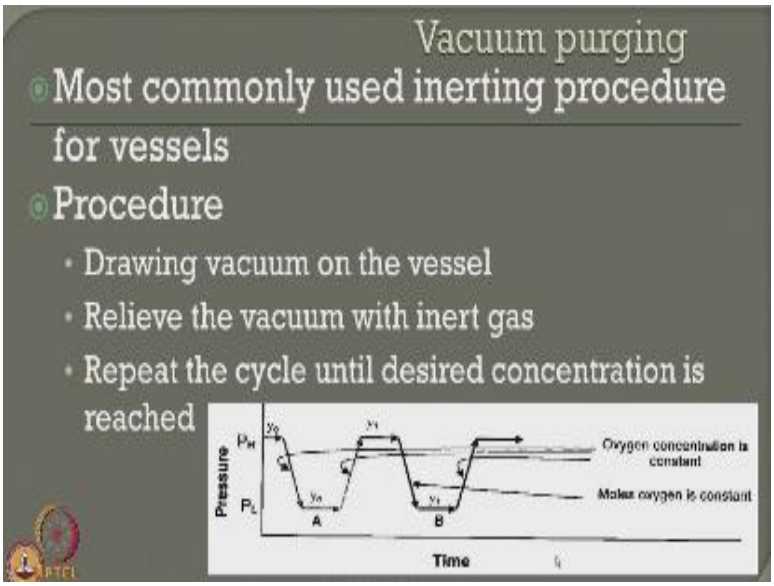

We will see one by one very quickly in case of vacuum purging let us see the figure available in the screen now initially it is one of the most common use method for inerting procedure for contained vessels, the procedure is very simple drawing vacuum on the vessel relieve the vacuum with the inert gas repeat the cycle until desired concentration is reached so the pressure is need to be dropped from high value the lower value desired for the specific range.

So while you are dropping the pressure or increase the pressure one has to maintain the oxygen concentration as a constant value while the more locks in contain is also remain to be content therefore the concentration keeps on changing from Y_0 to Y_1 to Y_2 as a number of cycles are changed from a to b and c and so on as a time progress.

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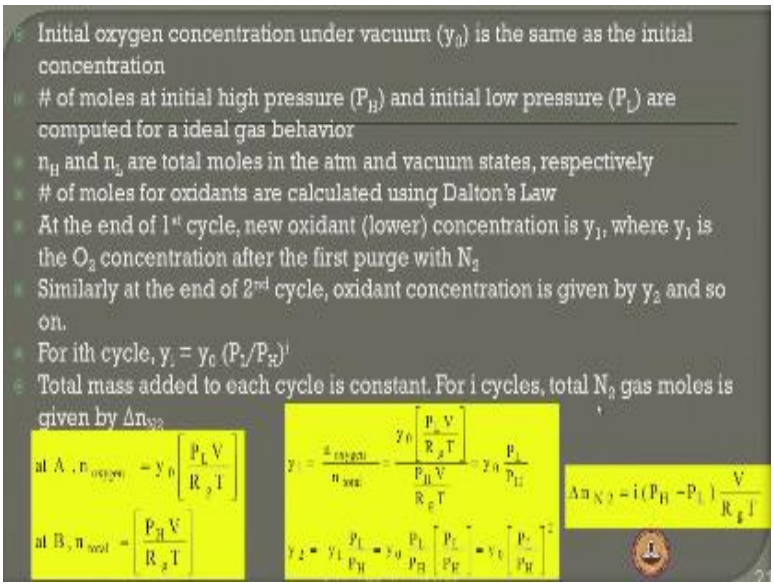

Initial oxygen concentration under vacuum which is Y_0 is the same as a initial concentration available in the fuel, number of moles at high initial high pressure P_H and initial low pressure P_L or computed for a ideal gas behavior, once it is known then n_H and n_l are in the equation available as total moles in the atmospheric and vacuum states respectively so for every concentration once you know the oxygen participation and the total moles one can always try to compute what is the concentration available at every level of change in the different cycle as Y_1, Y_2 and so on.

One can easily understand friends for finding out the concentration at Y_1 you need to know the value of Y_0 similarly finding out the value of Y_2 you need more avail of Y_1 so it is the subsequence step of purging is done with the help of this equations, the number of moles for oxidants are calculated using Daltons law at the end of the first cycle the new oxidant which is the lower concentration is $Y_1$where Y_1 is the oxidant concentration after the first purge with Y_2.

As you keep on purging you will see that the concentration changes from Y_0 to Y_1 and subsequently to Y_2 and so on, similarly at the end of the second cycle oxidant concentration is now given by Y_2 and so on FF for ith cycle the oxidant concentration Y_1 can be given by this

equation which depends on Y_0 as well as the pressure drop for the ith cycle, the total mask added to each cycle is therefore constant for i cycles the total nitrogen gas moles is given by Δn_2 which is given by this equation available on the right hand side of the equation in the slide.

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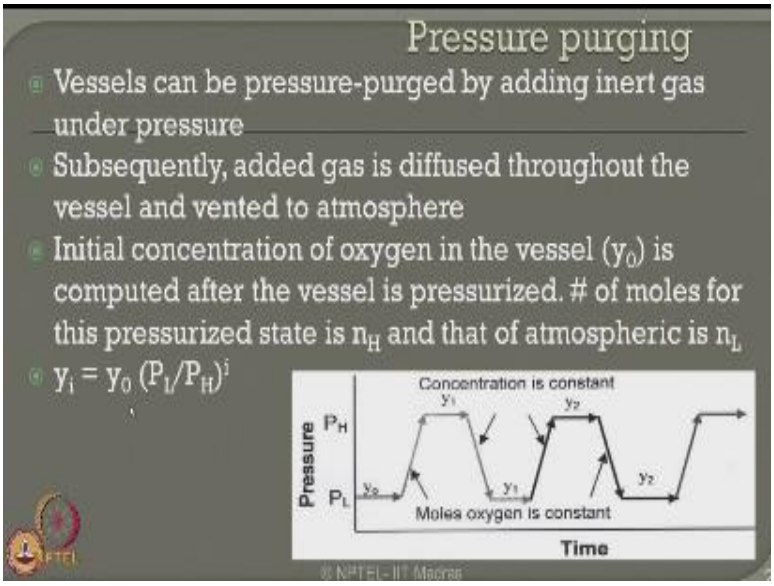

One can also do pressure purging in this case from the lower pressure value the pressure is increased to the concentration changing from Y_0 to Y_1 and so on as you see here, while we are increasing the pressure moles oxygen is kept constant and the concentration also maintain constant during the drop as well as pressure raise in number of cycles as you see in the picture. Vessels can be pressure purged by adding inert gas under pressure.

Subsequently added gas diffused throughout the vessel and vented to atmosphere the initial concentration of oxygen in the vessel Y_0 which is seeing here is computed after the vessel is specialized the number of moles for this special state is n_h and that of the atmospheric is n_l the oxidant concentration of the highest cycle Yi is given by the ratio of P_I versus P_H for I cycles with that of the initial value Y_0.

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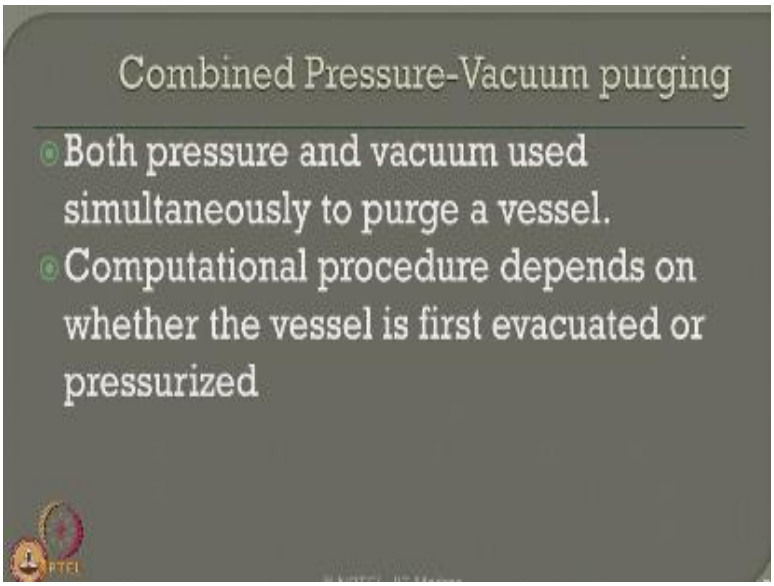

One can look combine for the pressure and vacuum purging as you see in the slide now both pressure and vacuum purging are use simultaneously to purge a vessel computation procedure depends on whether the vessel is first excavated or pressurized.

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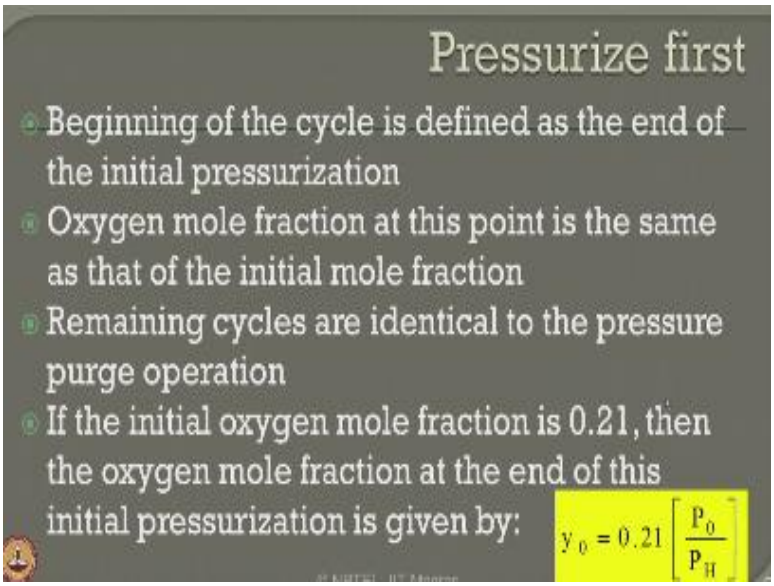

Let us say for example let us do the pressurizing first in that case beginning of the cycle is first defined as the end of the initial pressurization the concentration Y_0 is given by this value for just point 21 of the tough oxygen constant with P_0 and P_H value known to us the oxygen mole fraction at this point is same as that initial mole fraction available in the fuel, remaining cycles are identical to the pressure purging operation because we are specialized it first.

If the initial oxygen mole fraction is 0.21 then the oxygen mole fraction at the end of the initial pressurization is given by the equation as we see in the slide now.

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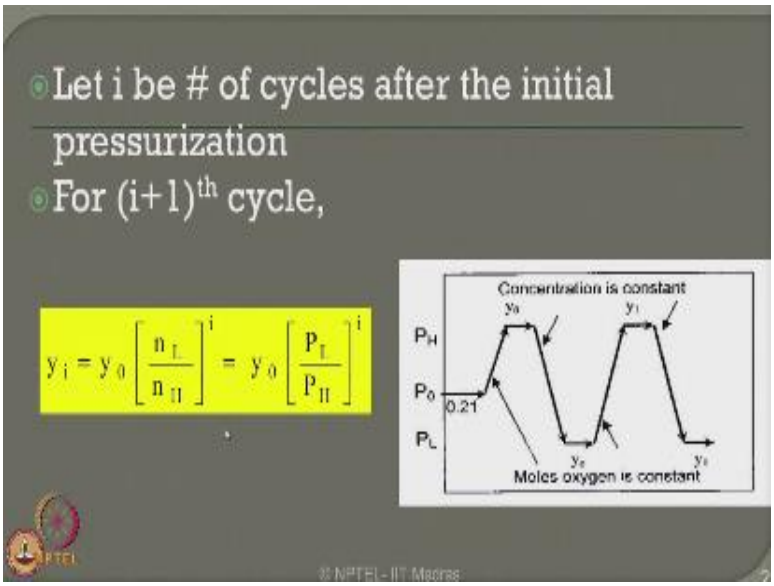

Therefore for # cycle after the initial pressurization the concentration is given by the equation as you see here.

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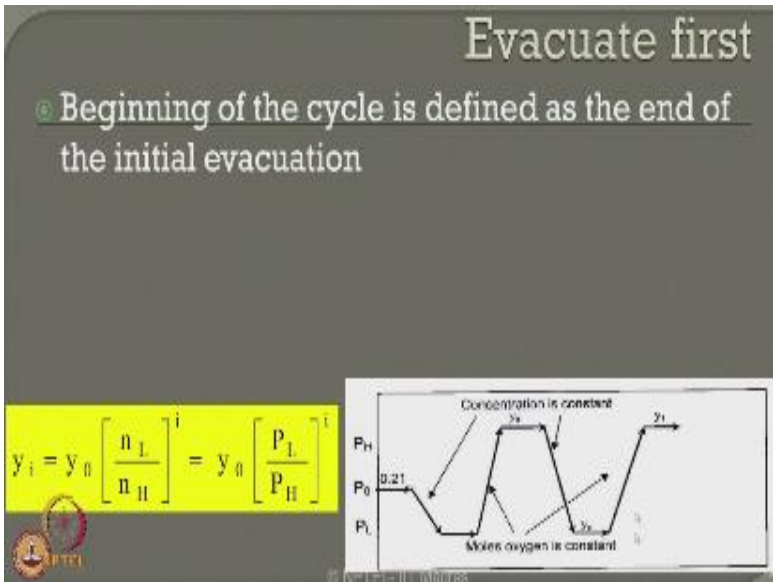

You want decides evacuate first beginning with the cycle is defined as the end of the initial evacuation, so you evacuate first and maintain the mole oxygen is constant and improve or change the concentration from Y_0 to Y_1 and so on.

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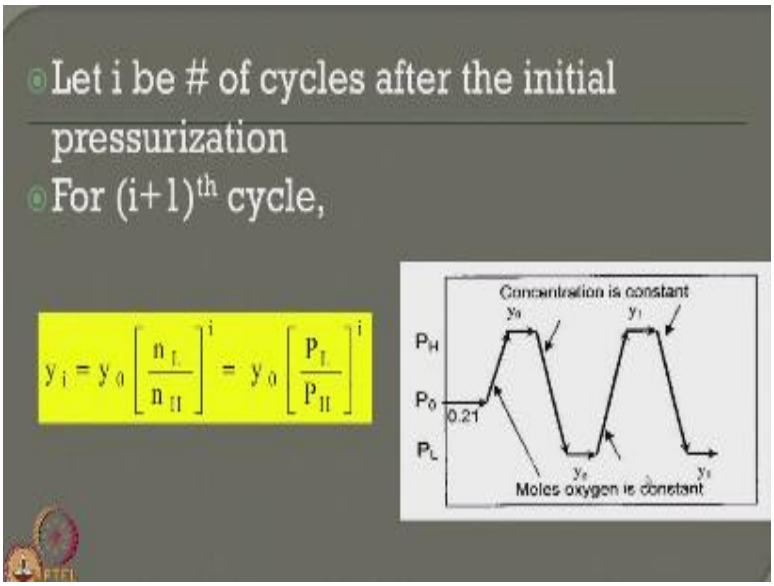

And see friends in the previous case initially pressurized and evacuate or purge.

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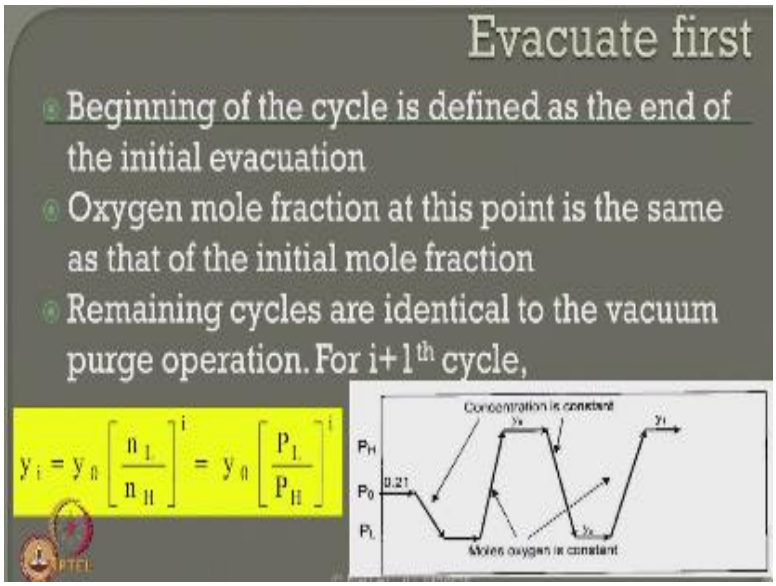

Whereas in this case you first evacuate and then pressurize so it is a combination of pressure and evacuation as you see in the previous examples the beginning of the cycle is defined as the end of the initial evacuation and oxygen mole fraction at this point is the same as that of the initial mole fraction and for the subsequence cycles of Y_i the remaining cycles identical to the vacuum pressure purging for $i+1^{th}$ cycle the value of concentration will be given as I see the equation here.

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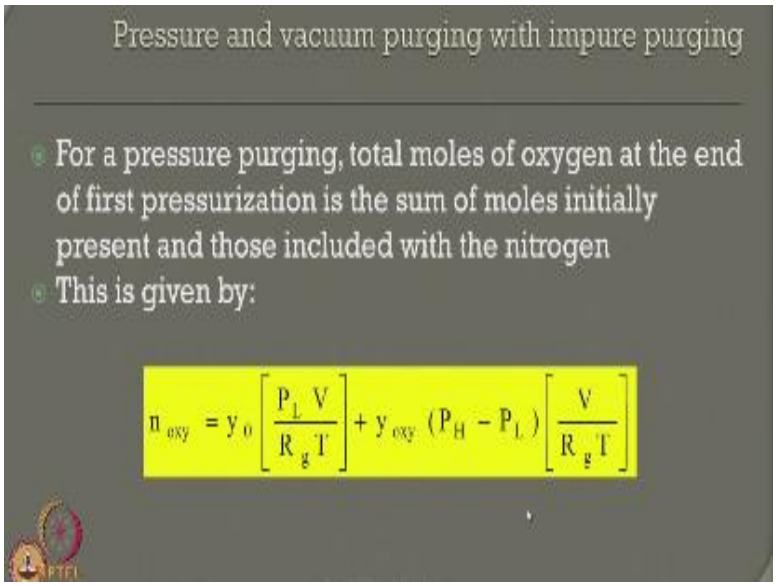

One can also be pressure and vacuum purging with impure purging for a pressure purging totals moles of oxygen at the end of the first pressurization the sum of moles initially present and those included with the nitrogen which can be given the equation available in the literature now where the number of oxygen moles concentration is given by the initial concentration with this equation plus the oxygen concentration available between the pressure difference as given by this relationship.

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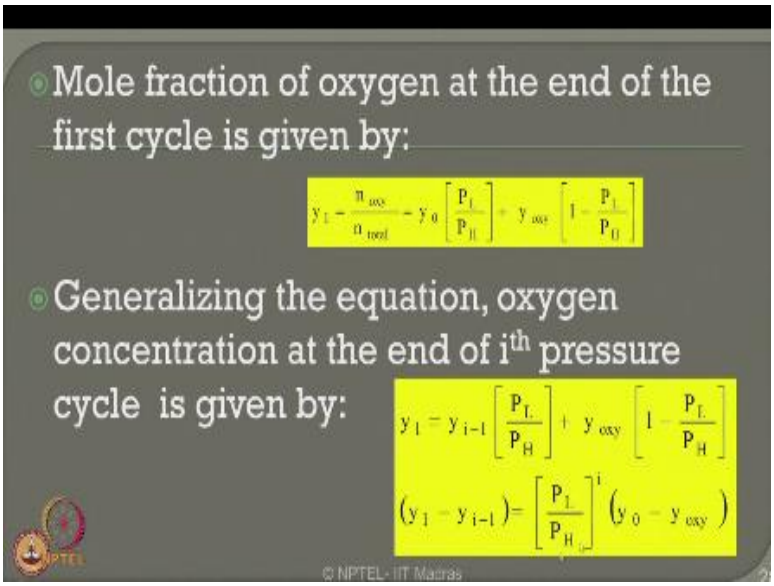

Mole fraction of the oxygen at the end of the cycle is therefore given by the n oxygen computed from the previous slide as I see here divided by n total which is the again relationship of as you see in the figure here now one can generalize this equation the oxygen concentration at the end of the i^{th} pressure cycle is therefore given by the relationship as you see in the equation in the slide now.

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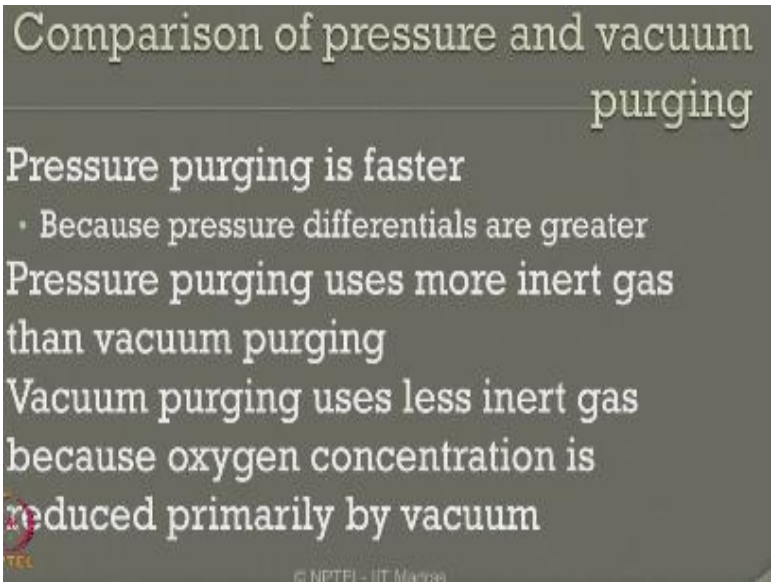

Now one can compare the pressure and vacuum purging and see what are the merits and de merits pressure purging is off course faster because pressure differentials or greater and activated faster pressure purging uses more inert gas then the vacuum purging vacuum purging using less inert gas because the oxygen concentration is reduced primarily by vacuum and not by at any replacement

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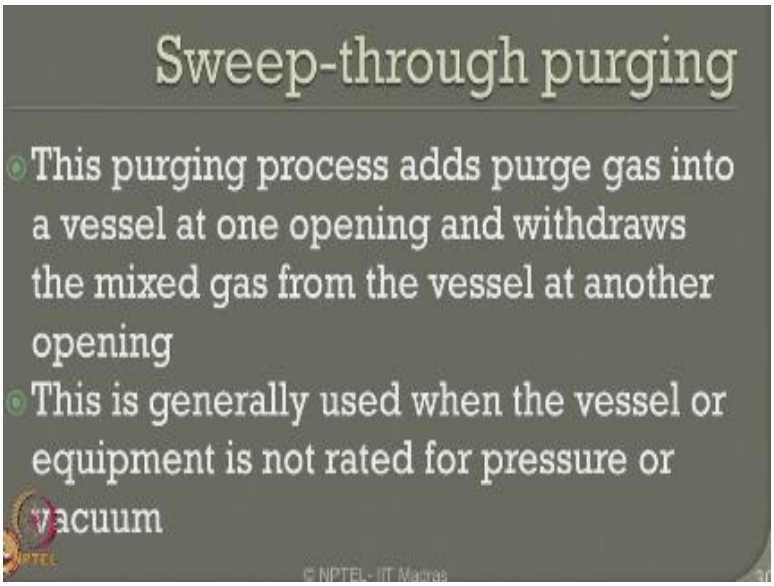

Alternatively one can also doo what is called sweep- through purging ,this purging process adds purge gas into a vessel at one opening and withdraw the mixed gas from the other end vessel in the another opening, this is generally used in the vessel or equipment is not rated for pressure or vacuum purging

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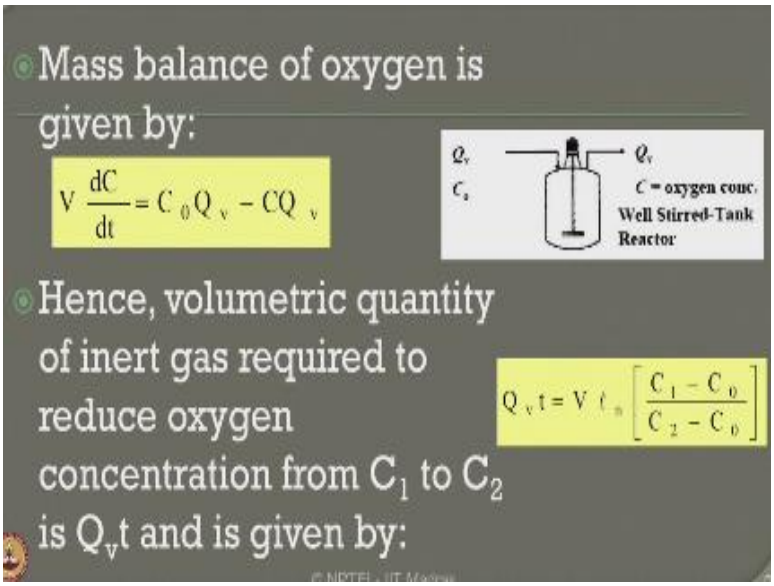

The mass balance of oxygen in this case is given by the equation shown in the slide now hence the volumetric quantity of the inert gas required to do oxygen concentration from C1 to C2 is given by QvT which is given in the equation as you see in the slide now here.

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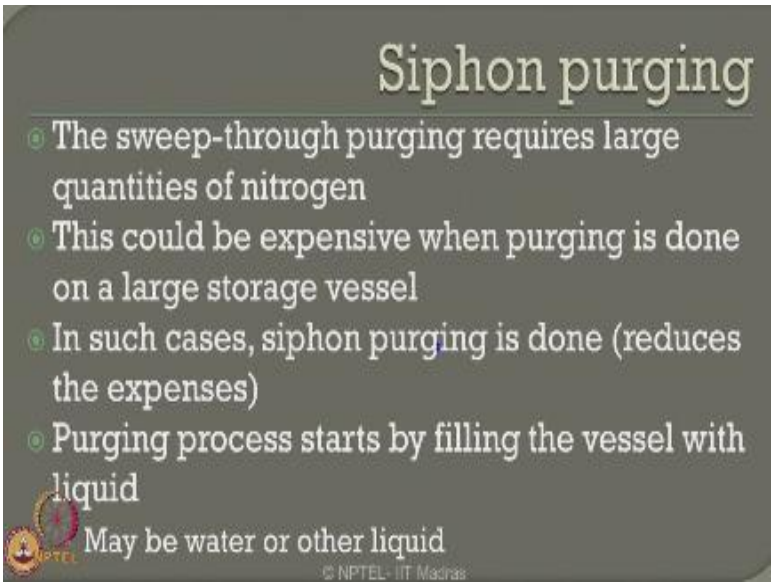

One can also do siphon purging as one of the design methods for reducing damages cause the explosion the sweep through purging requires the large quantity of nitrogen this could be expansive when purging is done on the large storage vessel in such cases people generally for siphon purging which reduces the expenditure because of purging process starts by the filling the vessel by the liquid this liquid may be the water or any other compatible liquid with that of the vessel.

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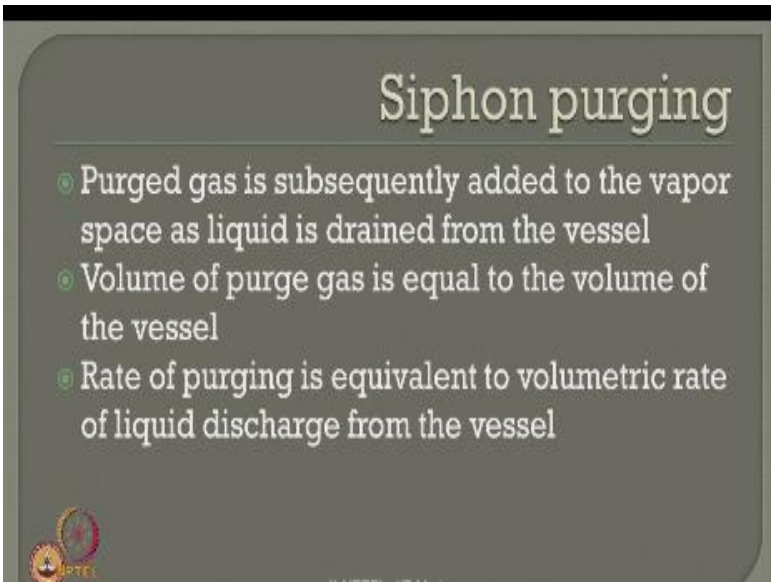

Siphon purging in this case the purged gas is subsequently added to the vapour space as liquid is drained from the vessel ,volume of purge gas is equal to the volume of the vessel rate of purging is off course equal to volumetric rate of liquid discharge from the vessel.

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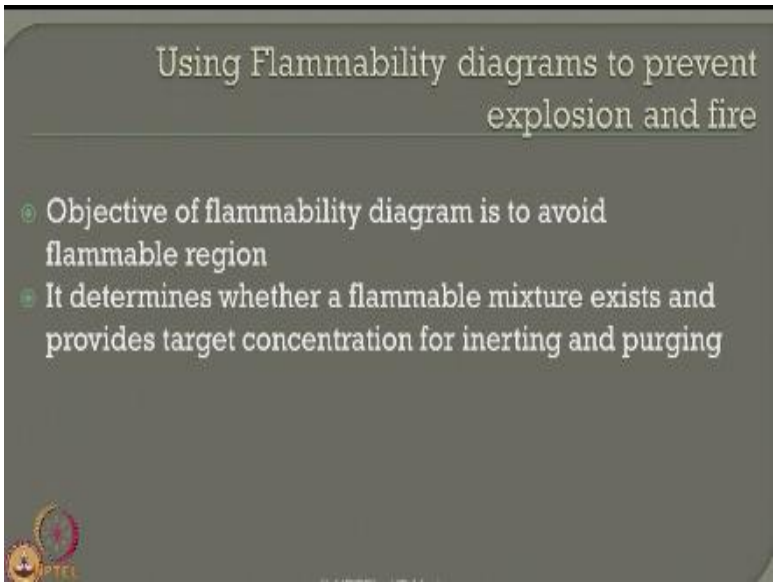

Alternatively friends one can also use flammability diagrams to prevent explosion and fires objective to avoid flammable region the flammable diagram determines whether the flammable mixture exists and provides target concentrations for inerting and purging.

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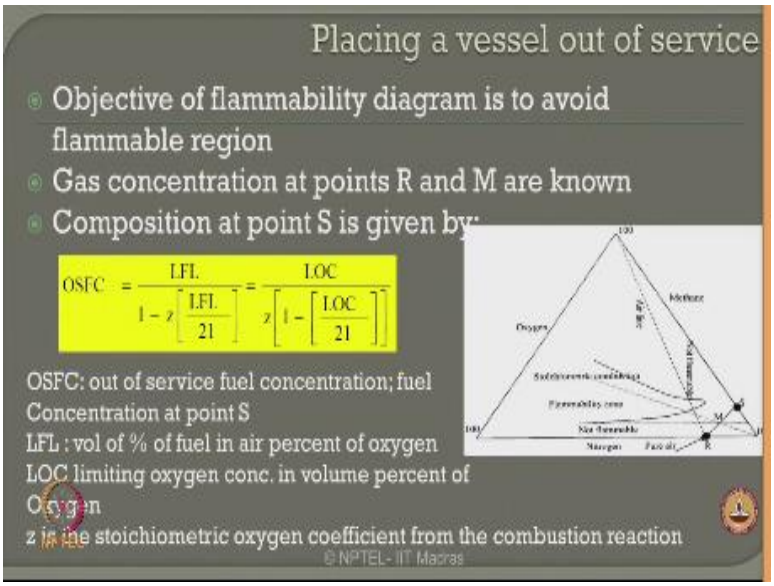

One can also use a technique called placing a vessel out of service so let us look at the flammability diagram here we recollect this it is called 3ams nitrogen, fuel and oxygen of the values varying from 0 to 100 ,and 0 to 100 in anti clockwise manner we know how to draw this particular flammable diagram in this case the diagram shown for a fuel which is methane ,objective of the diagram is to avoid the flammability we already know the flammable region is going to be this part which can be plotted easily depending upon the LOC and LFL and UFL of the fuel arm ,the gas concentration is the points R and M are known to be because these are the concentration available to be readily ,the composition of this at the point S can be computed using this equation.

So one can keep the out of service in the vessel by using this concentration where OSFC stands for out of service fuel concentration the fuel concentration point is collected as the point S below S on the fuel arm so one who like to know this value because I want to keep the vessel out of service in terms of this fuel concentration LFL of course the volume of present of fuel in air present of oxygen and LOC is a limiting oxygen concentration in volume percent of oxygen ,and of course we know in the equation Z is the stoichiometry oxygen coefficient from the combustion reaction of the fuel

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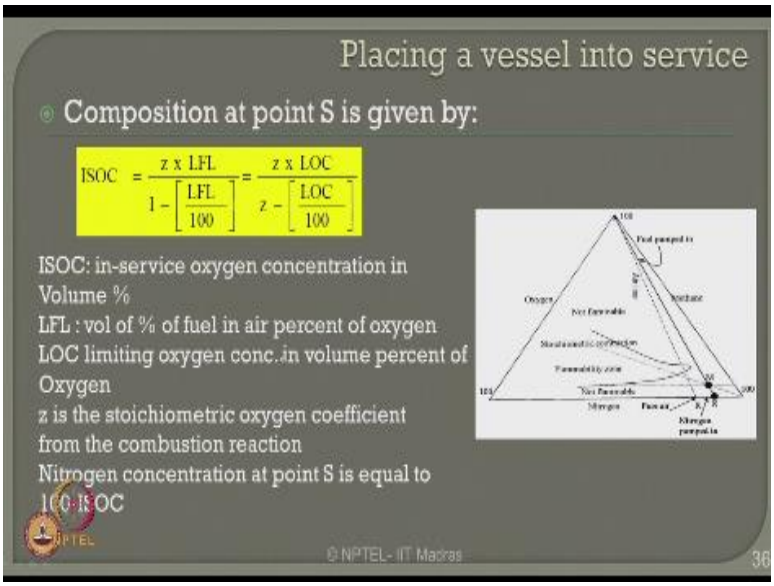

One can also place the vessel back in to service so I would like to know again the concentration available the composition at a point S now is given by this equation available in the screen where in this case ISOC stands for in service oxygen concentration in terms of volume % LFL of course the volume of fuel in present of oxygen LOC is a limiting oxygen concentration in volume of present oxygen and so on and Z of course the stoichiometry oxygen coefficient available for the specific fuel in terms of its reaction therefore the nitrogen concentration point S is equal to 100-ISOC where ISOC can be computed from this relationship.

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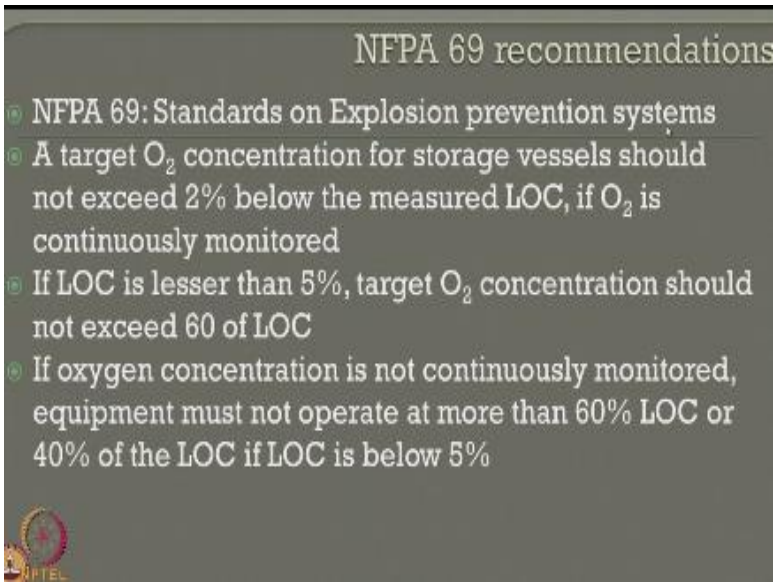

There are other methods available in the literature is given by NFPA69 recommendation s NFPA 69 is standards on explosions prevention systems a target oxygen concentration for storage vessels should not exceed 2% bellowed the measured LOC if oxygen concentration is contentiously monitored if it is not then it can be 5% of the target value ,if oxygen concentration is not contentiously monitored the equipment must not operate at more than 60% in LOC OR 40% LOC is below 5% available these are recommendation given by the standards and explosion prevention systems is practiced in oil gas industries.

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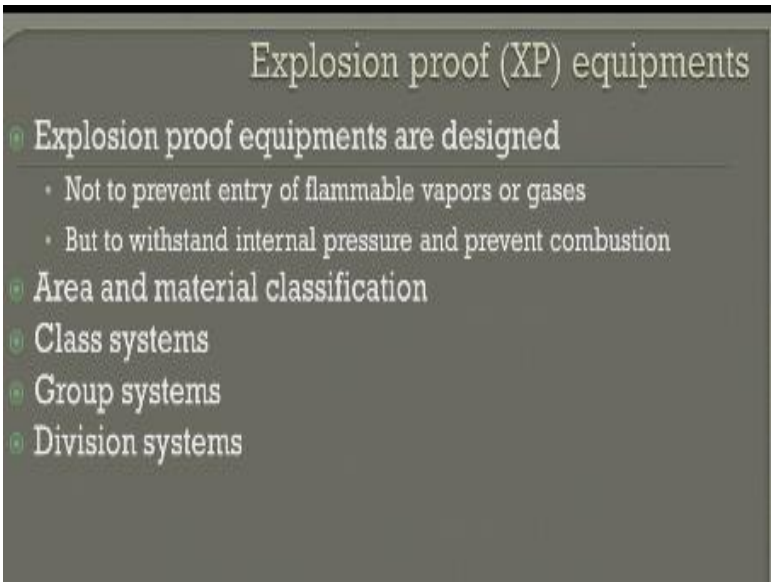

Friends alternatively one can also use explosion proof equipment's which are rated as XP equipment's explosion equipments are designed not to prevent entry of flammable vapours or gases but to withstand internal pressure and prevent combustion from these actions area and material classification can be done basically as explosion equipment proof there are different class systems available in the literature there are different group systems available ,there are different divisions systems available in the systems which will see one by one

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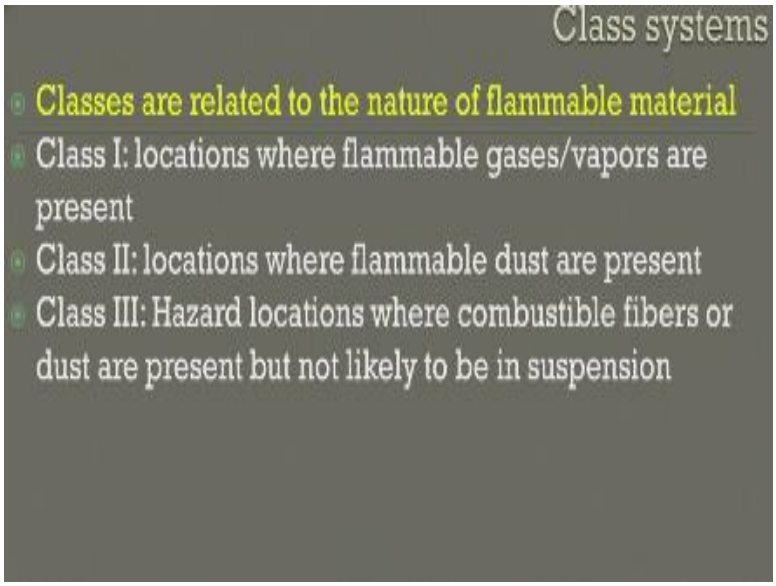

Class systems are related to the nature of flammable material class 1,2& 3 respectively show where flammable gases and vapour are present class2 shows locations where flammable dust is present class 3 shows hazards locations where combustible fibers or dust are present but not likely to be in suspension.

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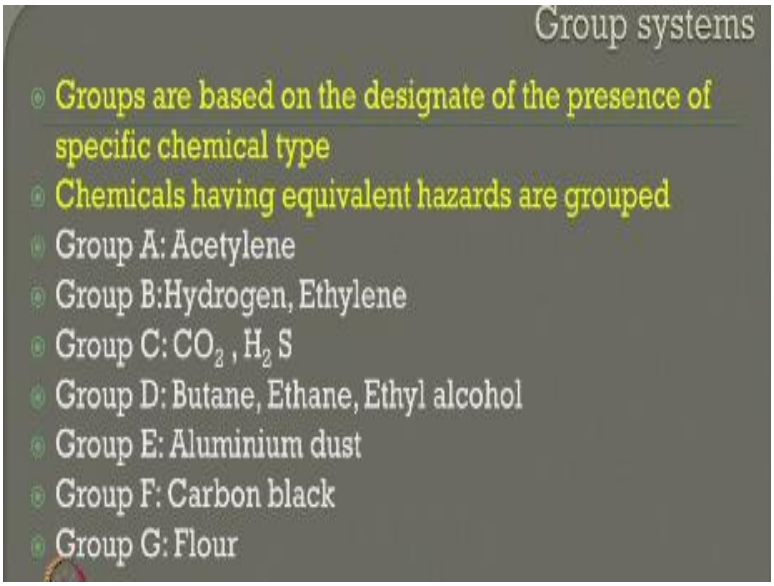

We talk about the grouping the systems groups are based on the designate of the presence of the specific chemical type chemicals having the equal hazards are grouped ,group A, B, C and so on A group has acetylene ,B hydrogen ethylene group C stands for carbon di oxide ,hydrogen sulphide group D butane, ethane, ethyl alcohol group E aluminum dust ,group F is carbon black group G is flour.

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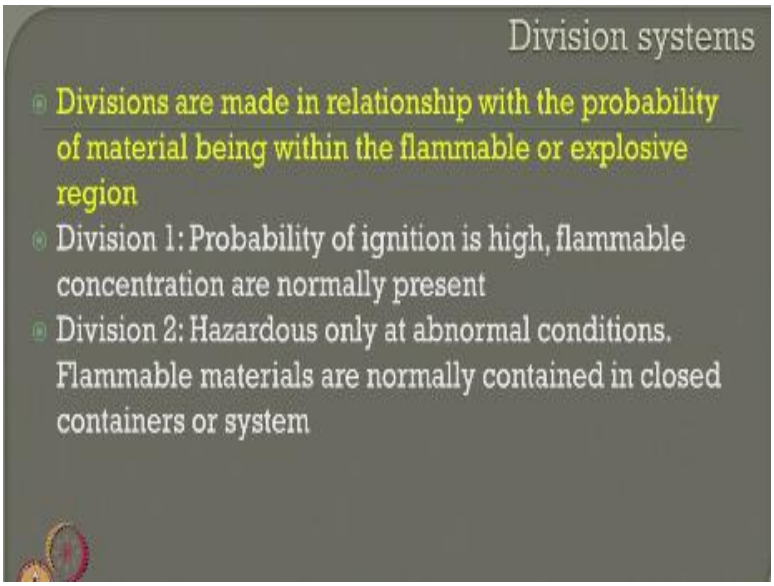

We can also have division systems has recommended by the guidelines given in the OS-ID divisions are made in relationship with the probability of material being within the flammable or explosive region division 1 stands for the probability of ignition is very high flammable concentration is normally present division 2 stands for hazardous only at abnormal conditions the flammable materials are normally contained in a closed containers in a given system and so on.

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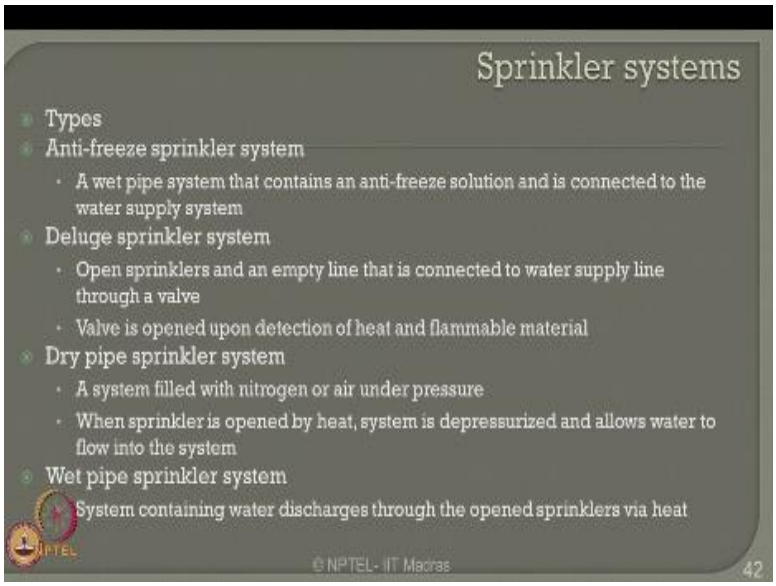

Lastly sprinkler system can also one of the tested design methodologies to prevent or reduce damages cause from explosions there are different types of sprinkler systems is available in the literature anti freeze sprinkler system which is defined as the mid type system that contains the anti freeze solution and it is connected to the water supply system can also a Deluge sprinkler system which consists of open sprinklers and an empty line that is connected to the water supply line through a valve the valve is open upon detection of heat and flammable material and water sprinkle inside dry pipe sprinkler system indicates the system fill with nitrogen or air under pressure the sprinklers open by heat system is depressurized and allows water flow in to the system.

We can also have wet pipe sprinkler system which contains water discharges through open sprinklers by our heat

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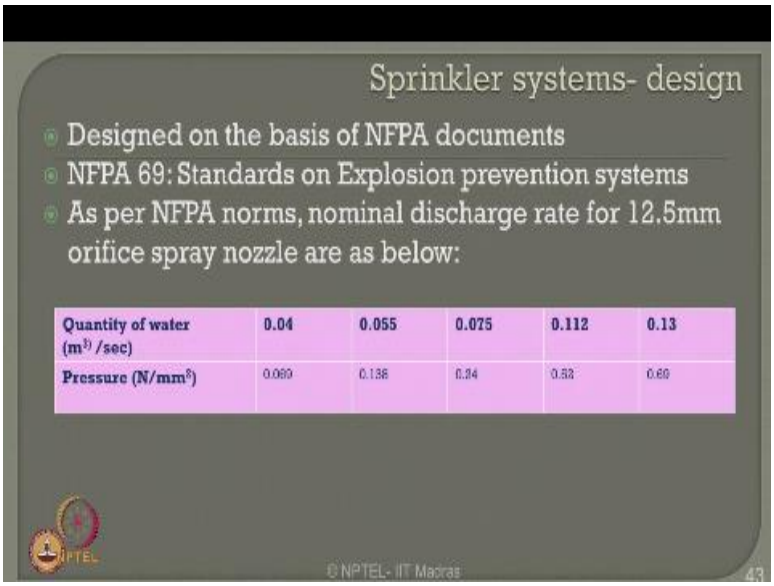

So sprinkler system can also be done one should aim at the minimum quantity of water required at specific pressure available from the literature as a guide line there are based on NF PA recommendations NFPA standards on explosion prevention systems the quantity of water which is given in m^3 /sec and the corresponding pressure equipment in terms of N/mm^2 is given as a guide line for designing the sprinkler system ladies and gentlemen so as per the NFPA norms nominal discharge rate for 12.5.mm orifice nozzle given in the table as shown in the figure

So friends in this lecture we discuss about different explosions models and corresponding design methods by which we can either mitigate or reduce the damages cause from the explosions of different nature we also seen some of the guidelines given by the directorate we also seen some of the parallel methods by which the mitigation can be achieved in terms of damages caused by explosion most importantly estimate the damage arising from explosion we find out the t & t equalize method which is most commonly used in the literature for oil and gas industries thank you very much.

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