Health, Safety and Environmental Management in Offshore and Petroleum Engineering

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Module – 03
Accident modeling, risk assessment and management
Lecture – 03
Flammability diagram

Today will be the third lecture in module 3, where we are going to learn how to draw a flammability diagram.

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This is the third lecture in module 3, where we are focusing on Accident Modeling Risk Assessment and Management. We already said for a fuel mixture to catch fire, we need to know the flammability characteristics of the mixture, they are important further we also know in case of a fire triangle, which is got 3 arms the ignition source being one of the arms fuel and air if any one of this is absent. Obviously, a mixture or a fire hazard will not be present in the given system, but unfortunately in a process industry like oil and gas industry, we have all these 3 present in abundance. Therefore, it is very difficult really to avoid a fire hazard situation in a given process mechanism.

So, to really understand, how we can mitigate or control the consequences which can occur from fire accidents? We need to understand the flammability characteristics of the given fuel mixture to better understand the flammability characteristics, one generally prefers to draw what we call flammability diagram. Flammability diagram actually determines the flammability diagram.

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If you draw determines, whether a given mixture is flammable or not flammability diagrams can also be used effectively to control fire accidents. They can even prem prevent they can even prevent fire and explosion of flammable mixtures basically flammability diagram depends on the chemical species, flammable diagram depends on the chemical composition of the mixture temperature and pressure it also requires the pre requisite for drawing a flammability diagram could be the chemical composition of a mixture.

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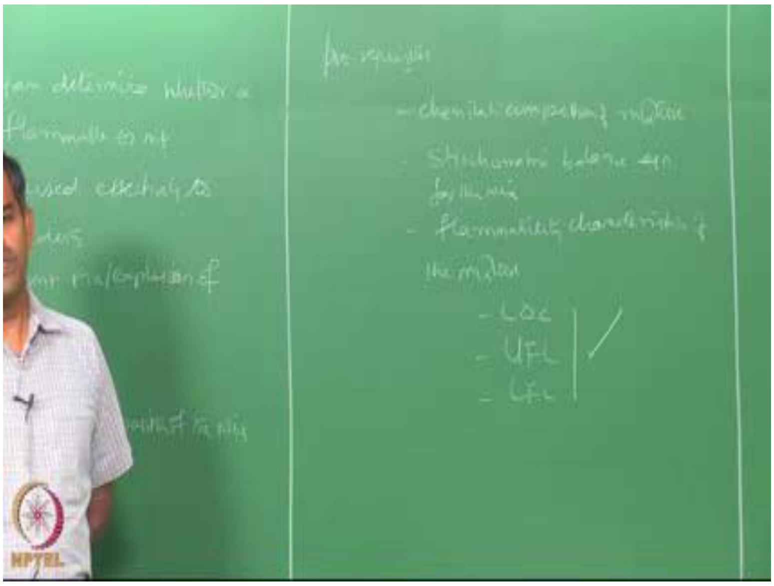

In our case we would like to draw for a hydrocarbon you should also have the stoichiometric balance equation for the mixture.

The flammability characteristics of the mixture namely limiting oxygen concentration upper flammability limit lower flammability limit should be known, let us quickly see how a typical flammable diagram looks like then we will draw a flammability diagram for a hydrocarbon example interestingly as you see in the fire triangle flammability diagram also has three arms.

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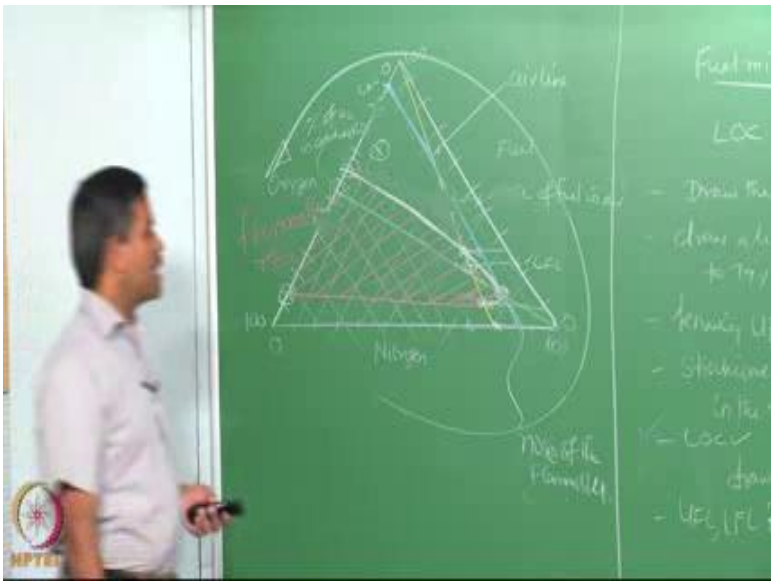

This arm is a nitrogen arm, this arm is fuel arm and this arm is oxygen arm, interestingly there is an order by which you can draw this triangle because these triangle need to be graduated and you need to have calibrate this triangle starts from 0 to 100, may be that is it similarly again 0 to 100 similarly again 0 to 100. Of course, it has got series of lines which can actually be useful in marking the plots in between, so there is an order by which this triangle is formed. This is anti clockwise 0-100, 0-100, 0-100 nitrogen fuel oxygen that is how this triangle is formed for a given fuel mixture for a given fuel mixture.

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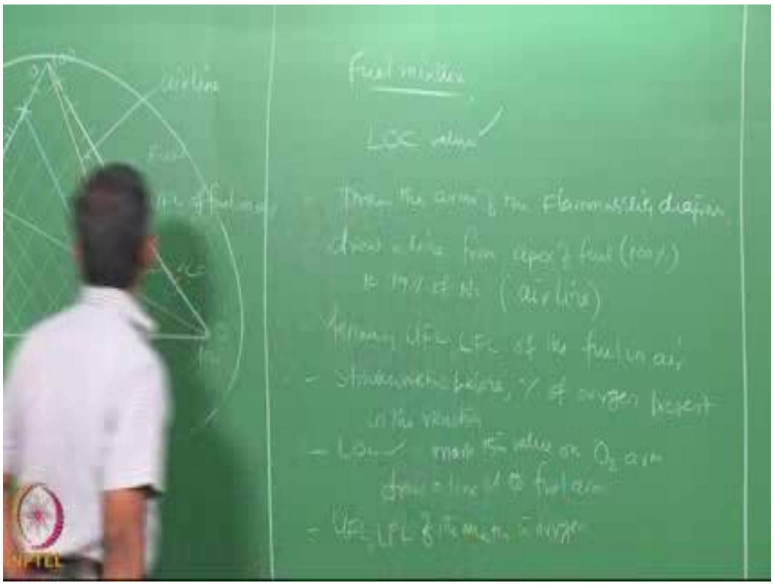

If I know the limiting oxygen concentration value, we know limiting oxygen concentration is the minimum percentage of oxygen content, which is required for the fuel to remain flammable or supply continuous flame while it is burning.

So, what we do here is we draw a air line. So, first step would be draw the arms of the flammability diagram as shown. So, that is an order 0-100, 0-100, 0-100 nitrogen fuel oxygen, one can change this arm cycle also, but let us not fix up to change that, let us have this as a basis the second could be draw a line from apex of fuel, apex in sense 100 percent to 79 percent of nitrogen, where that is generally the presence of nitrogen in the atmosphere. So, let us say this is 90, this is 80, 79 is somewhere; here I mark it here draw a line. Let me draw a line from this line is called air line. So, this is what is we call as an air line then, the upper flammability limit and the lower flammability limit of the fuel in air of the fuel in air. So, mark that percentage of upper and lower flammability limit for example, here project this percentage on the air line. So, these are the upper and lower flammability limits of the fuel in air. So, this is upper flammability limit of the fuel in air this is lower flammability limit of the fuel in the air. So, what I do is I mark these points on the fuel arm project it to the air line.

I also know from the stoichiometric balance the percentage of oxygen present in the chemical reaction or chemical combustion I mark that percentage may be this value on the oxygen join this with the apex of the nitrogen 100 percent. This point is percentage of oxygen in combustion, which you will get from the stoichiometric balance equation I will take up an example and I will draw it again no problem. So, I have these points marked on the airline, airline is this, another line which showing a stoichiometric balance equation from which I know the oxygen percentage contribution in the combustion join that apex of nitrogen. Which is 100 percent I also know the limiting oxygen concentration present or required for this fuel remain flammable.

Let say that values somewhere here which I mark I draw a line, mark this point on the oxygen line that is LOC draw a line parallel to the fuel arm draw a line parallel to the fuel assume that these 2 lines are parallel. So, mark this value on the oxygen arm draw a line parallel to fuel arm we will draw them in parallel to fuel I also know the UFL and LFL of the mixture in oxygen. So, mark those points mark those points these are the points of LFL and UFL of the mixture or of the fuel in oxygen percentage is on oxygen. So, mark them. So, these are the points what I have got to mark and then draw joining them as to get the flammability diagram.

So, what I do is wherever that here wherever the LOC line this point is LOC intersects the stoichiometric balance line that will be the nose of the flammability diagram then, this point join the line connecting the ULF to ULF and this and then back here. So, this becomes my flammable region. So, if my fuel concentration lies somewhere here it is evident from this figure that I mixture will not catch fire. So, flammability diagram is the first instant of information given to the service engineers whether the fuel is or the fuel mixture is flammable or not let say I will.

So, pick from this point somewhere here drawn like this like this let see like this and we all know that flammability or the flammable region is between the upper and lower flammable regions and this becomes a nose which is an intersection of the air LOC line with that of a stoichiometric balance equation. So, 1, 2, 3, 4, 5, 6 and 7, which are projected from this are required to draw the flammability diagram a typical diagram is also shown in the screen now please look at the screen.

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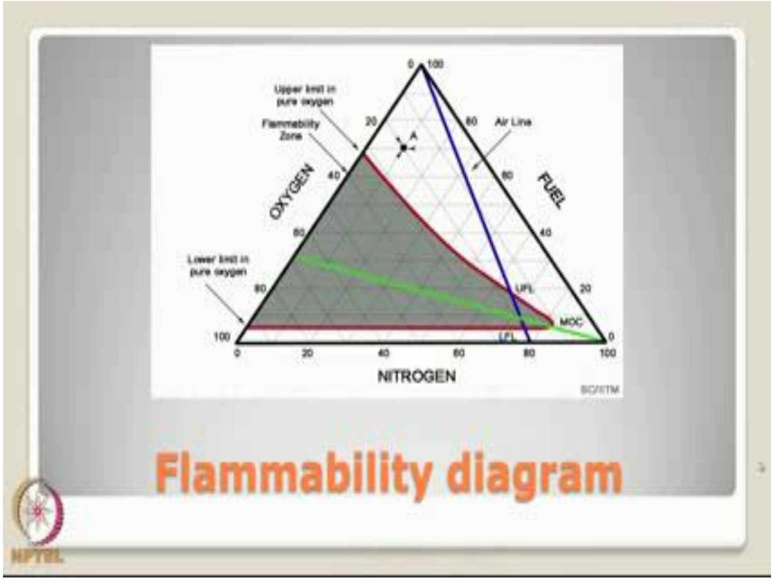

You will get a typical diagram of the flammability diagram shown in the screen which is as same as what I explained in the black board here.

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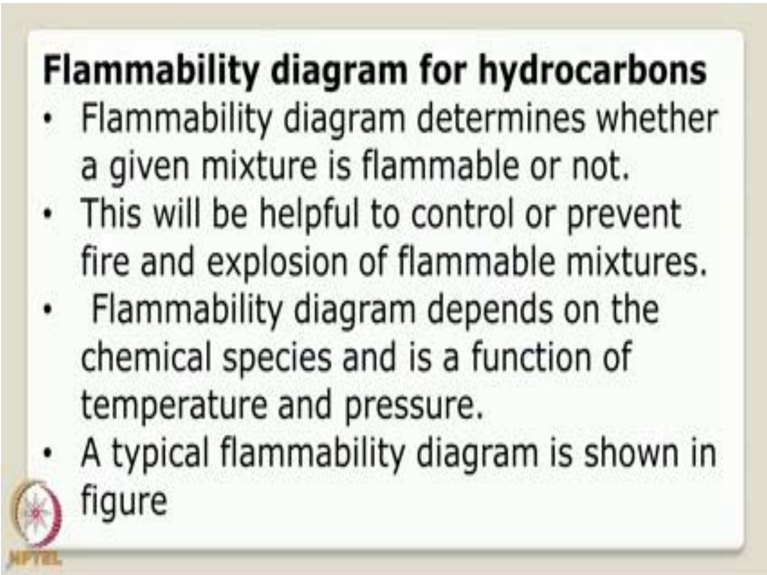

So, flammability diagram is useful in understanding whether the fuel mixture is flammable or not.

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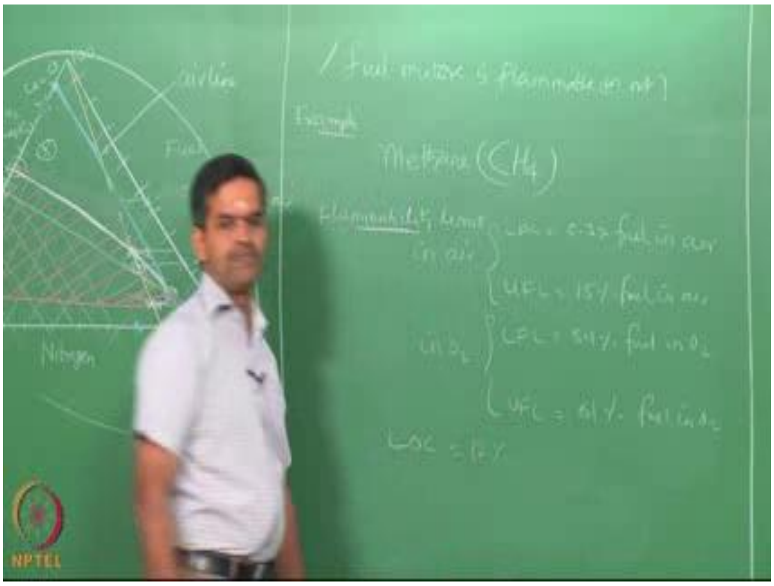

One can get from the flammable diagram. So, we already understood the procedure of drawing the flammability diagram. Let us try to take an example the example is going to be a typical hydro carbon and I will draw a flammability diagram on the right hand side here let say we are going to draw the flammability diagram for methane which is CH4 the flammability limits for methane which are available in chemical engineering handbook in air these values are known which is the lower flammability is 5.3 percent fuel in air and the upper flammability is about 15 percent fuel in air. Now the flammability limits in oxygen is also known for this particular hydrocarbon the lower flammability limit is about 5.1 percent fuel in oxygen and the upper flammability limit is about 61 percent fuel in oxygen for the specific mixture the limiting oxygen concentration is found to be 12 percent. So, these are the given data now to draw the flammability diagram.

Next step could be to write the equation for combustion.

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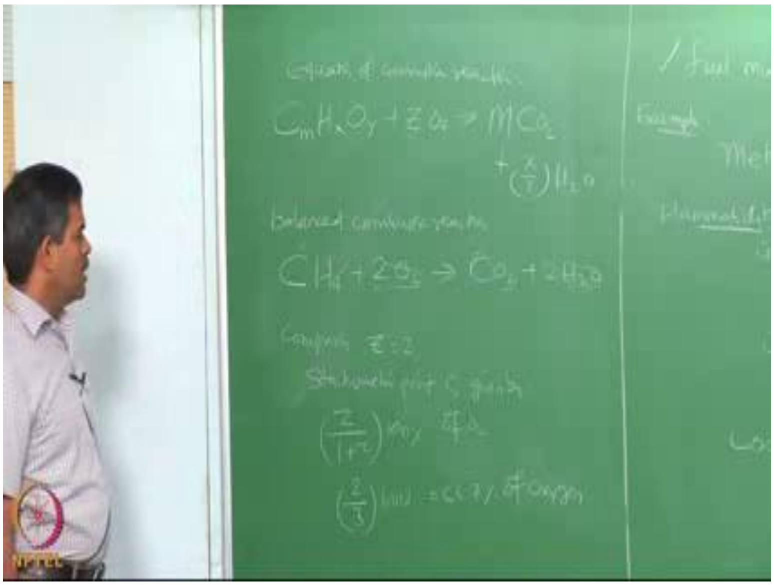

So, let us say m moles of c h concentration with x and oxygen concentration with y plus z value of oxygen concentration further gives me MCo 2 plus x by 2 off H_2O. Now the balanced combustion reaction is CH_4 for my problem plus 2, O_2 gives me CO_2 plus $2H_2O$, you can see here hydrogen is 4 hydrogen is 4C a is 1 and 1 oxygen is 4, 2 and 2. So, its balanced equation I want to compare these 2 equation the generic equation this is for my specific mixture which is methane comparing these 2, I can always say the z concentration comparing you know z is actually equal to 2. Now I want to find the stoichiometric point which is given by z by 1 plus z of 100 in terms of percentage in oxygen of or percentage of oxygen, let us say. So, in my case this become 2 by 3 of 100 percent which is about 66.7 percent of oxygen which will help me to really find the stoichiometric point on the oxygen of now, let us try to draw the flammability diagram as we explained. So, it has got three arms.

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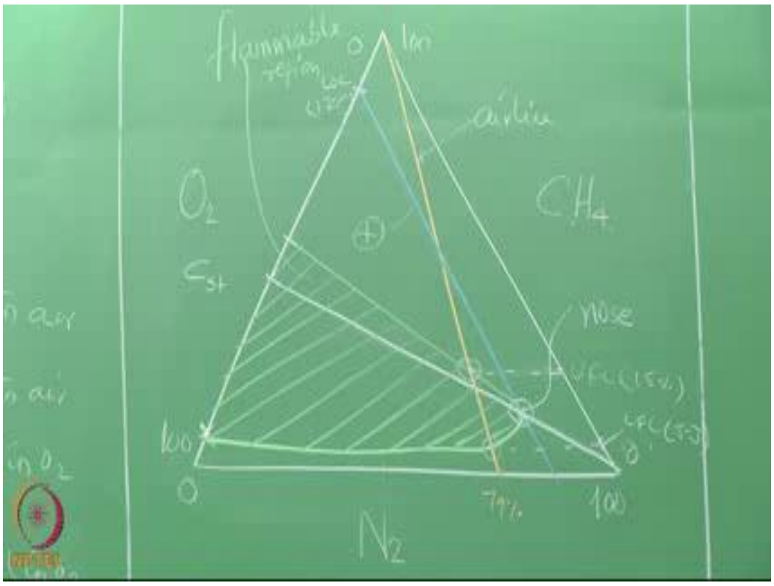

Let us draw the three arms let us mark this arm nitrogen this arm fuel and this arm oxygen this is 0 to 100, 0 to 100, 0 to 100 that is an order we have to follow.

The next step should be join the apex of the fuel with let say 79 percent of nitrogen. Let us draw a line what we call as air line. Now I mark the ULF and LFL 15 and 5.3 of fuel on the air line. So, I must mark 5.3 and 15; on the fuel projected to air let me. So, I got these points this corresponds to ULF 15 percent this corresponds to LFL 5.3 percent I also know the LOC is 12 percent of oxygen limiting oxygen concentration. So, mark 12 percent, 0 then 12 is somewhere here. Let us mark LOC which is 12 percent draw a line parallel to the fuel arm let us draw a line parallel to the fuel line a line parallel to fuel line we have drawn a line parallel to fuel line. We also know the stoichiometric point of oxygen is about 66.7 percent. So, 0 is here may be 70, 66 may be here let us say this point. So, I call this as the stoichiometric point on the oxygen arm I pick up this point and join this point to apex of nitrogen. So, let us join this point to the apex of nitrogen this point.

Wherever this line wherever this line is intersecting my limiting oxygen concentration line I mark that as the nose of the curve that is the nose of the curve further I also mark LFL and ULF of the fuel in the oxygen arm which I will mark them here sixty one percent somewhere here. So, these are the ULF points mark this point and mark this point these are ULF and LFL points of the fuel in oxygen earlier there were ULF and LFL of the fuel on air therefore, I marked on the fuel projected to on air now I know this points on the oxygen arm itself I marked this points. So, now, I can draw the flammability diagram by joining this point pass through this point pass through this point come to the nose pass through this point and come here.

So, now, the hatched portion is flammable region for example, by any chance you add more oxygen by oxygen supply or change the chemical composition of the mixture by the process or change the limits of the mixture because of temperature variation we already know the LFL ULF limits change with increase and decrease in temperature and pressure we already saw that in last lecture. So, we adjusting the temperature and pressure in the processing industry or the process line by changing the chemical composition of the mixture because of adding some ingredients in the process or by adding oxygen fresh oxygen or fresh air into the process line one can always bring down the concentration of this in such a manner that the concentration will not fall in the flammability region at all.

So, the flammability diagram is actually firsthand information or a person to know whether the given mixture lies in the flammability region or not because these values are for ideal situation for a given mixture of methane. So, I can always play with operational temperature and pressure in such a manner that this does not fall in the flammability region of the mixture this can be very intelligent way of planning or averting accidents because of fire.

So, flammability diagram is a very interesting information which can be an useful tool for people to realize and understand whether the given mixture composition is flammable or not that is how this diagram is generally drawn further to this once the flammability region is located and the mixture lies in the flammability region then there is always a possibility that the mixture can explore or can catch fire in both the cases it has got an energy what we call ignition energy.

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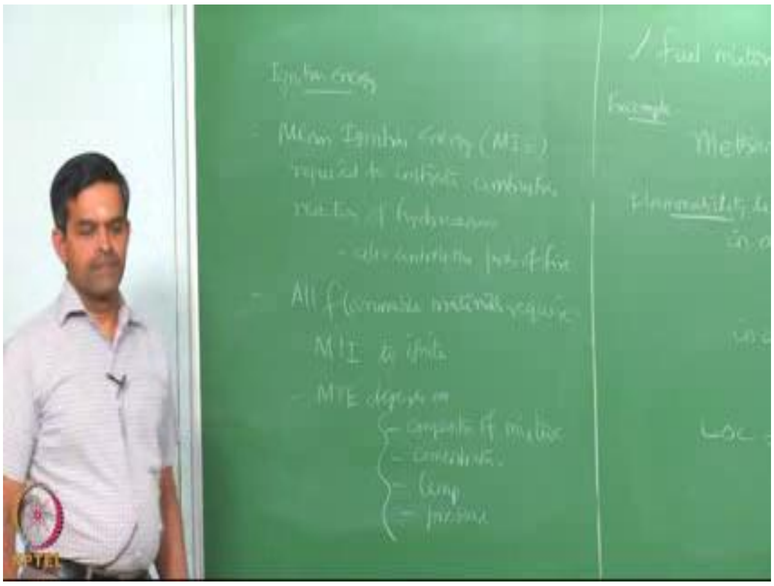

The minimum ignition energy that is MIE required to initiate combustion reaction of hydro carbons of mixture let us say hydro carbons also controls the probability of fire therefore, all flammable materials should require a minimum ignition energy. So, that is a concept here. So, all flammable material require MIE to ignite or catch fire this MIE minimum ignition energy depends on couple of factors the composition of the mixture the concentration temperature and of course, pressure for a verity of chemicals available in the process industry.

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The minimum ignition energy for chemicals is actually available in chemical engineering hand book I will show you quickly a table, kindly look at the table shown on the screen.

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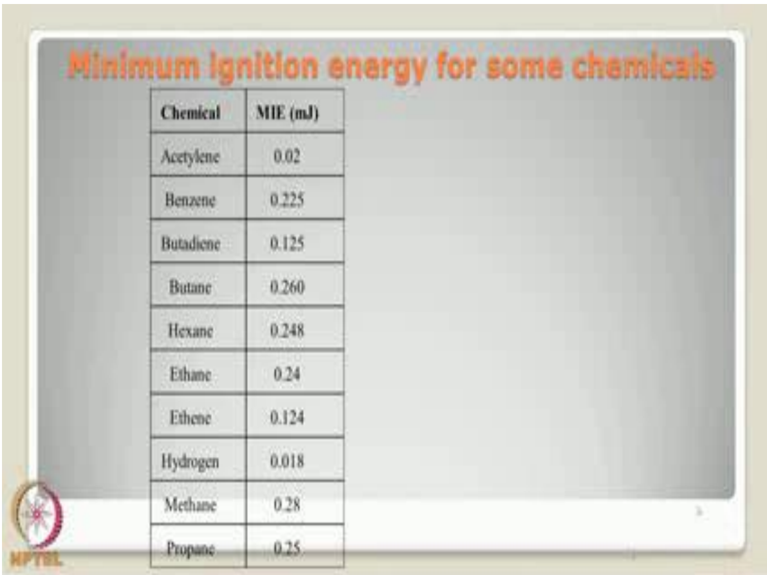

Minimum ignition energy for some chemicals

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

Now, for different chemical like acetylene benzene butadiene butane hexane ethane ethene hydrogen methane and propane the minimum ignition energy which is required to set this mixture to become a flammable set is given in milli joules which is expressed in the table. So, this is available to us.

Therefore once this is known then one can always control the possibility of ignition through many ways. So, to understand the control of ignition sources one must understand what are those possible initiating ignition sources what are the possible initiating ignition source present in a process industry. So, please pay attention to the table shown on the screen now.

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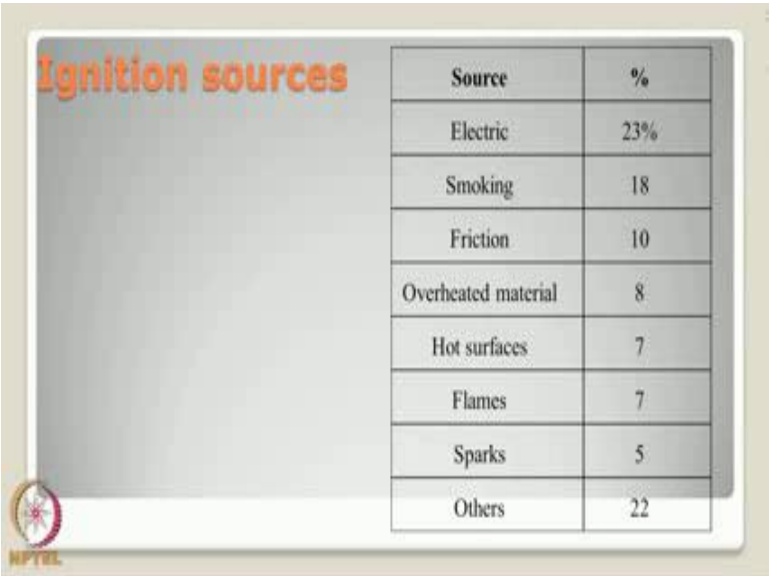

Source	%
Electric	23%
Smoking	18
Friction	10
Overheated material	8
Hot surfaces	7
Flames	7
Sparks	5
Others	22

There are verities of sources which are commonly present in any working plant and their percentage contribution in terms of source of ignition is initiated are given here electric source is one of the major cause or responsible item for initiating ignition. Which is contributing to about 23 percent of course, smoking also adds eighteen percent if we put together man made accidents. Let say smoking friction flames and sparks put together this will exceed about, let us say close to 45 percent and if you add also a wrong design in terms of electric or over heated material where the temperature gauges are not properly installed and there is no proper ventilation and there is no proper electric circuit design which is carefully planned for the plant then the total source of igniting or initiating the ignition could be close to as high as 80 percent.

So, therefore, friends accidents may be fire and explosion essentially in offshore industry or any process industry in general are caused because of negligence either in the design state or in the process of production state. It is nothing to do with environmental factors at all except that either wind direction of the wind speed is favoring the propagation or dispersion, then the consequences because of fire and explosion could be disastrous otherwise initiation always happens from the man made mistakes, may at the design stage or maintenance stage or during the production stages we have to realize this.

Therefore, given the flammability diagram understanding the mixture characteristics understanding the possible minimum ignition energy required for the specific composition and knowing the ignition sources one can easily play with these factors to really know how fire and explosion in the given composition mixture can be greatly controlled. So, flammability diagram becomes a very important source of information for accident prevention and also to learn about the possibility or probability of accidents in terms of fire and explosion in any process industry. Of course, the fire arm or the fire triangle where all the 3 arms are in evidently present in offshore industry will always make this industry highly vulnerable for fire and explosion.

Therefore, one have to carefully design the electrical layout one has to have enough working environment comfortable in terms of open air ventilation and one should also carefully see that small mistakes like sparks flammable substances inventory being stock etcetera should be avoided. So, that if that is the case or an exercise or an example consider in mind while approaching safety in process industry it is very very evident that fire and explosion accidents can be easily averted or can be at least controlled even if they occur.

Thank you very much.