Health, Safety and Environmental Management in Petroleum and offshore Engineering

Prof. Dr. Srinivasan Chandrasekaran

Department of Ocean Engineering

Indian Institute of Technology, Madras

Module No. # 03

Lecture No. # 08

Fire and explosion modeling

Flammability diagrams

Ladies and gentlemen, now we look at lecture-8 on module-3, which is now covering fire and explosion modeling. In this lecture, we will discuss you step by step, how to draw a flammability diagram.

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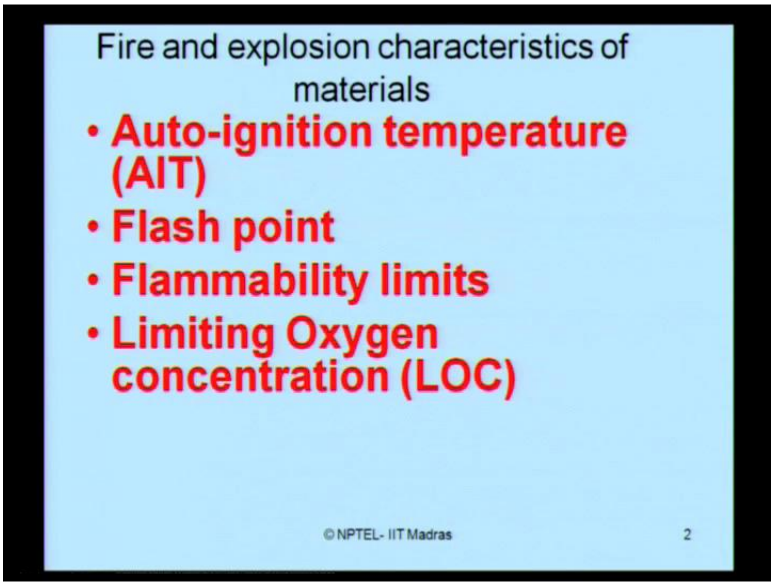

Fire and explosion characteristics of materials

- Auto-ignition temperature (AIT)
- Flash point
- Flammability limits
- Limiting Oxygen concentration (LOC)

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Before we do that, let us quickly revise, what are the essential characteristics of material with respect to fire and explosion modeling. We have understood, what is an auto ignition temperature, what is a flash point, what are flammability limits for a given material or a mixture, and what do we understand by limiting oxygen concentration.

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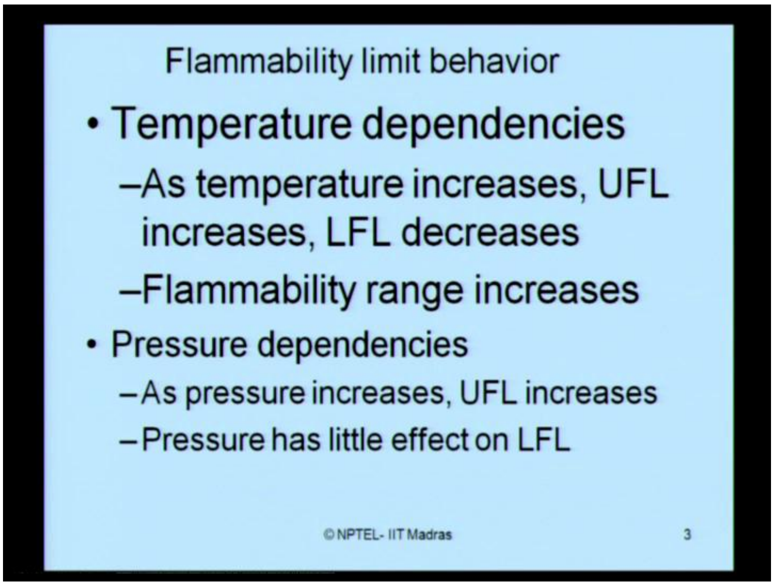

Flammability limit behavior

- Temperature dependencies
  - –As temperature increases, UFL increases, LFL decreases
  - –Flammability range increases
- Pressure dependencies
  - –As pressure increases, UFL increases
  - –Pressure has little effect on LFL

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We have also understood the flammability limits behavior, which is temperature dependent and pressure dependent. We have seen that, as temperature increases upper flammable limit increases, whereas lower flammability limit decreases. On the other hand, we can say very easily that the flammability range keeps on increasing with increase in temperature. On the other hand, look at the pressure dependency, we have already shown that the upper flammability level increases as pressure increases, but the pressure has less influence on the lower flammability limits.

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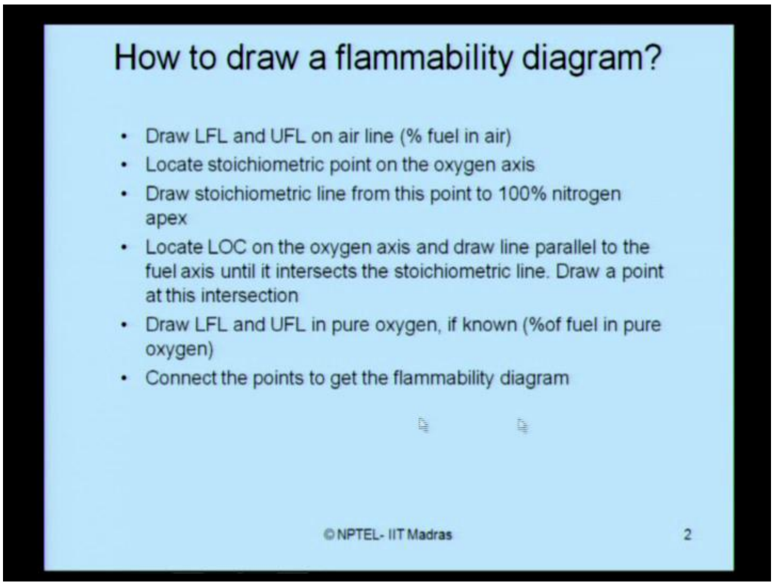

How to draw a flammability diagram?

- Draw LFL and UFL on air line (% fuel in air)
- Locate stoichiometric point on the oxygen axis
- Draw stoichiometric line from this point to 100% nitrogen apex
- Locate LOC on the oxygen axis and draw line parallel to the fuel axis until it intersects the stoichiometric line. Draw a point at this intersection
- Draw LFL and UFL in pure oxygen, if known (%of fuel in pure oxygen)
- Connect the points to get the flammability diagram

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Now, ladies and gentlemen, let us see, how to actually draw a flammability diagram? The following steps are very important draw the lower flammable limit and upper flammable limit on the air line. We have already seen in the last slide, a flammability diagram basically has three arms of a triangle; one arm contains the fuel; one arm contains oxygen; other arm contains nitrogen. So, they have been specifically marked a (0, 100), (0, 100,) and (0, 100) in specific order. Now, for a given fuel, you understand to know the lower flammable limit and upper flammable limit; mark these limits on the air line. I think you appreciate, if I say air line, because you understand what I mean by an air line; air line is nothing but the line joining the apex of oxygen arm to about 79 percent on the nitrogen and 80 percent nitrogen arm; that is a simple line which we call as an air line. So, mark LFL and UFL on the air line.

Locate the stoichiometric point on the oxygen axis; this can be obtained from the chemical reaction or the combustion reaction of the fuel. Draw the stoichiometric line from this point to apex of the nitrogen arm. Locate the limiting oxygen content of the oxygen axis and draw line parallel to the fuel axis until this intersects the stoichiometric line, mark this point of intersection. Now draw LFL and UFL in pure oxygen, if they are known for a specific fuel which you are considering for the problem. Basically it is nothing but the percentage of fuel in pure oxygen, if you know that try to mark them on the pure oxygen arm. Connect the points to get the flammability diagram.

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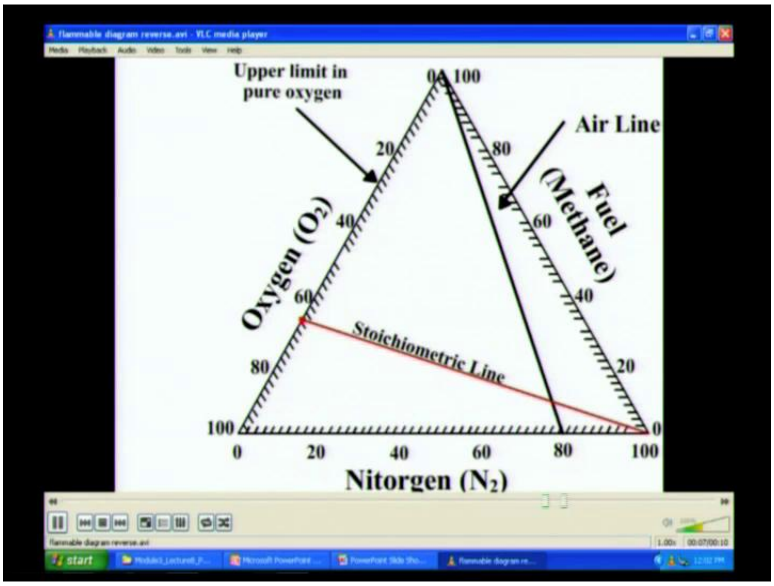

Now, let us see interestingly an animation, how to draw the flammability diagram? Here is the animation to draw the flammability diagram. So, you draw the nitrogen arm; you draw the fuel arm; you draw the oxygen arm; you draw the air line; you locate the stoichiometric point; draw the stoichiometric line; locate the UFL and LFL on the fuel arm; mark LOC and draw the line, and try to find what is the concentration of fuel on pure arm joint, this points to get the boundary of the flammability diagram. So, this region is what we call as flammable region.

Once again, let us try to understand how to draw this flammability diagram, but in reverse order. Let us you are drawn the diagram, I am just explaining in a reverse order. Just to know how you are drawn.

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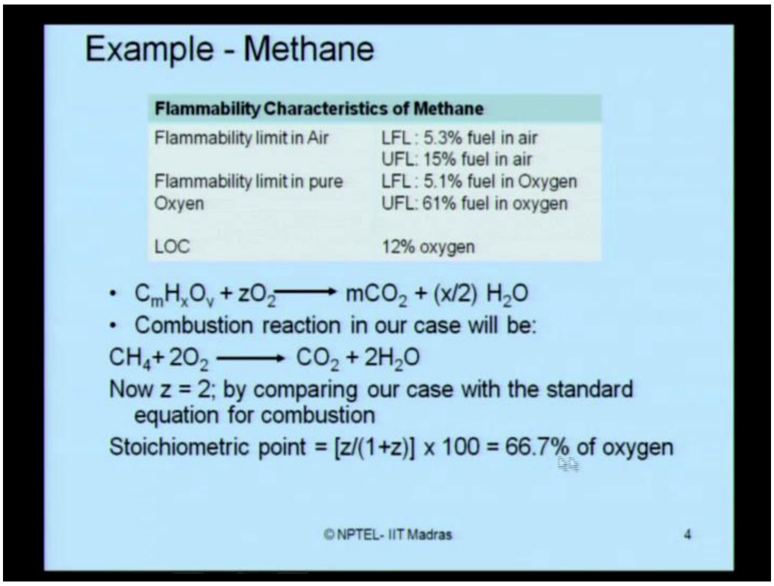

Example - Methane

Flammability Characteristics of Methane	
Flammability limit in Air	LFL : 5.3% fuel in air UFL: 15% fuel in air
Flammability limit in pure Oxyen	LFL : 5.1% fuel in Oxygen UFL: 61% fuel in oxygen
LOC	12% oxygen

- $C_mH_xO_y + zO_2 \longrightarrow mCO_2 + (x/2)\ H_2O$
- Combustion reaction in our case will be:

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

Now z = 2; by comparing our case with the standard equation for combustion

Stoichiometric point = [z/(1+z)] x 100 = 66.7% of oxygen

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If you want to draw the flammability diagram for the specific mixture, let us say, for example – Methane, Identify the flammability characteristics of methane, which is available in the standard literature. The flammability limit of the fuel in air LFL and UFL are given in the literature. The flammability limit in pure oxygen for the mixture is also available in the literature, and of course, the limiting oxygen concentration is taken as 12 percent of oxygen. So, this becomes my combustion reaction for the chemical, which I am considering or for the fuel which I am considering comparing this chemical combustion reaction which will be this is general expression; this is a specific expression for my specific example of CH 4. Comparing these two equations, I can easily say my z is basically 2; now for z equal to 2, the stoichiometric point can be computed from a simple expression like this, which gives me 66.7 percent of oxygen.

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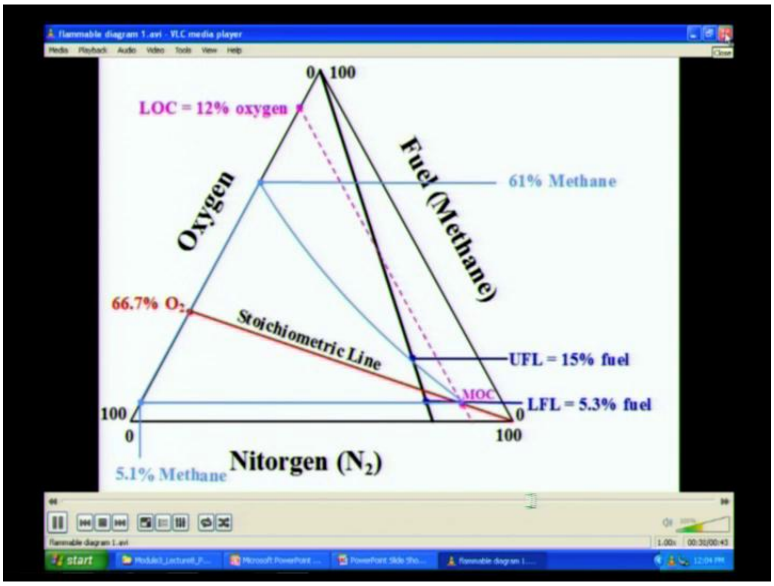

Now, once I get this for all the LFL and UFL values in pure oxygen and in air. I already know for methane. Let us try to draw the flammability diagram again for this given example, I draw the nitrogen arm; I draw the methane arm now; I draw the oxygen arm; I locate the airline; I locate the stoichiometric line; I locate LFL and UFL on the fuel arm; I also locate the LOC; I locate the pure oxygen arm of the fuel, join the boundary and get flammability region. This is how I draw my flammability diagram for methane.

Let us for more understanding, let us see this diagram in a finished format, and look at the reverse steps of this diagram. I have already drawn the diagram, now I am seeing how I have drawn this diagram for better understanding. Ladies and gentlemen, you must have now understood how to draw the flammability diagram for a given fuel mixture.

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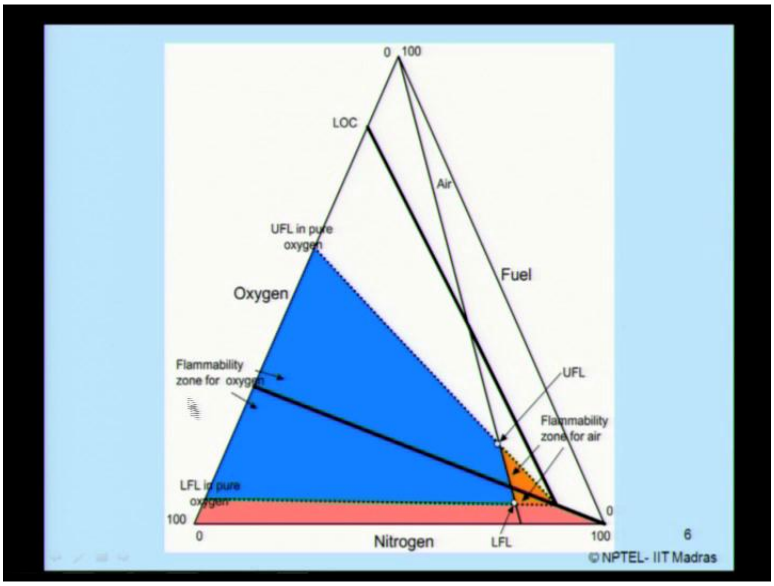

This is the completed diagram for specific fuel. We already know, this is the fuel arm 0 to 100; this is the oxygen arm 0 to 100; nitrogen arm 0 to 100. The numbering of this has a specific order; it is anticlockwise (0, 100), (0, 100), (0, 100) - nitrogen arm, fuel arm, and oxygen arm. When you know this try to draw what we call as airline, which is 79 percent of nitrogen, draw that with apex of the fuel or origin of oxygen and draw a line call this as airline. Then for the fuel arm, you already know the LFL and UFL values in pure oxygen as well as on the fuel.

Let it intersect the airline and get these points, get the intersection stoichiometric line with that of the LOC, get the nose of the curve, and this becomes flammability region in air, because this is my air zone. So, this part basically is air zone; this part is basically the oxygen zone. So, flammability zone for oxygen is this blue one; the flammability zone for air is the red one. So, if you have the oxygen concentration reduced then the flammability region can be highly reduced.

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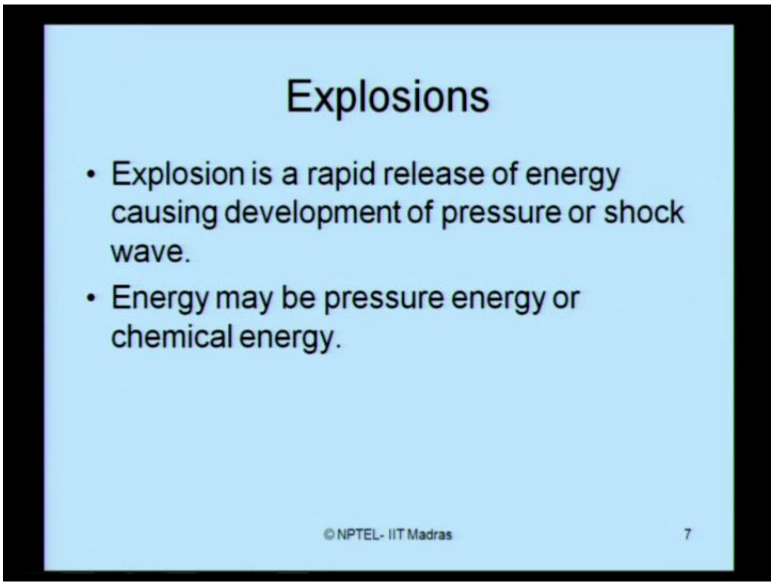

Explosions

- Explosion is a rapid release of energy causing development of pressure or shock wave.
- Energy may be pressure energy or chemical energy.

When you look at the explosion models, there are some basic definitions, which we have got understand. Explosion is actually a rapid release of energy causing development of pressure or a shock wave. The energy may be pressure energy or a chemical energy.

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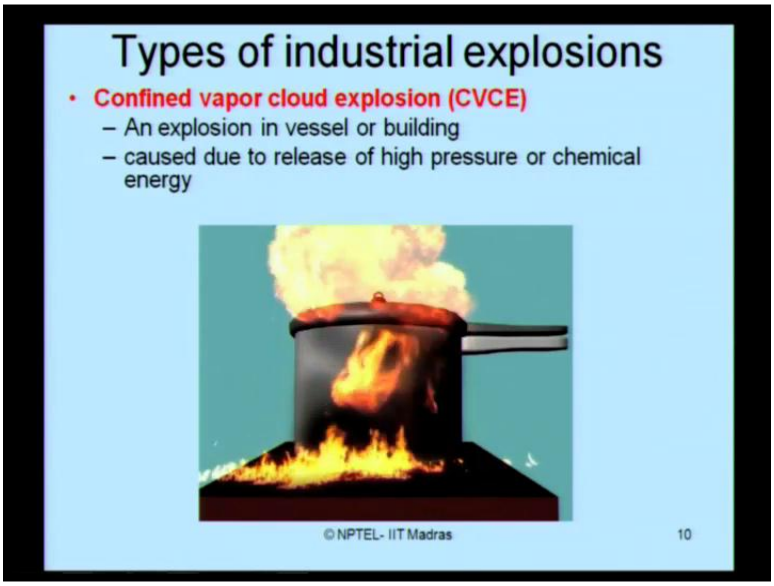

Types of industrial explosions

- **Confined vapor cloud explosion (CVCE)**
  - An explosion in vessel or building
  - caused due to release of high pressure or chemical energy

There are different types of industrial explosion, which we now describe one by one. The first one is what we call as confined vapor cloud explosion – CVCE. This is an explosion which could occur in a container vessel or a building. This is essentially caused due to release of high pressure or a chemical energy, for example, I have a contained vessel, the pressure in the contained vessel is increasing and that could result in an explosion. This kind of explosion is what we generally call as confined vapor cloud explosion.

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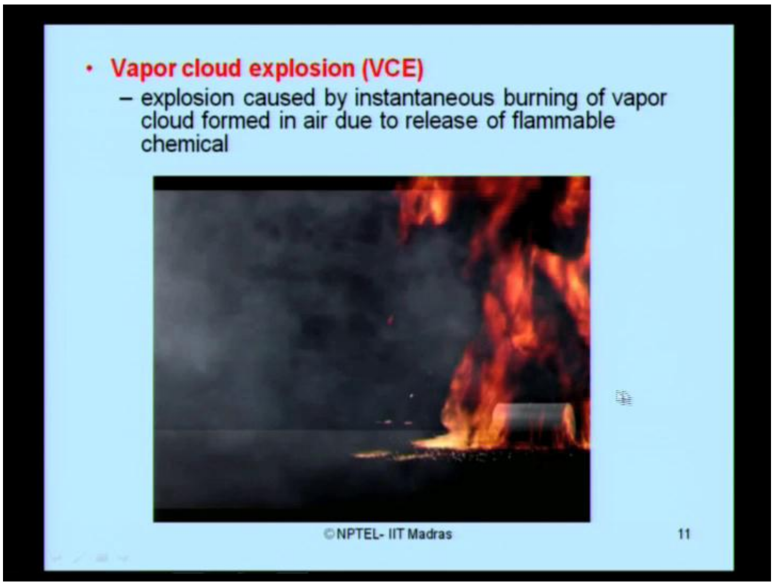

- **Vapor cloud explosion (VCE)**
  - explosion caused by instantaneous burning of vapor cloud formed in air due to release of flammable chemical

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The second type of explosion is simply called vapor cloud explosion. The confined part is removed from the definition. So, this is an explosion caused by instantaneous burning of a vapor cloud, which is formed in air due to release of a flammable chemical. So, there is a flammable chemical which has been released in air that is resulted in a cloud which we call as a vapor cloud and that explodes by some source of ignition. So, I have a cloud and this ignites; this is what I called as vapor cloud explosion.

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- **Boiling liquid expanding vapor explosion (BLEVE)**
  - Explosion caused due to instantaneous release of large amount of vapor through narrow opening under pressurized condition

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The third kind of explosion is what we call as BLEVE, which is expanded as boiling liquid expanding vapor explosion. Now, in this case, the explosion is mainly caused due to instantaneous release of large amount of vapor through a narrow opening under pressurized condition. I have a contained vessel; I have an increase in pressure in the vessel and there is a narrow opening through which the large amount of vapor is instantaneously released; that will result in a special kind of explosion, what we call as a BLEVE. So, the pressure is increase in the vessel and there is the narrow opening through which it will get released and that causes the explosion; this is what we call as BLEVE.

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- **Vented explosion (VE)**
  - Explosion due to high speed venting of chemical

The fourth kind of explosion is what we called as vented explosion. This is an explosion which is caused mainly due to high speed venting of chemicals. So, I have a chemical, this is released in the atmosphere at a very high rate and that results in an explosion, what we call as a vented explosion. We can see here that is there is instantaneous release of large amount of chemical from the vent.

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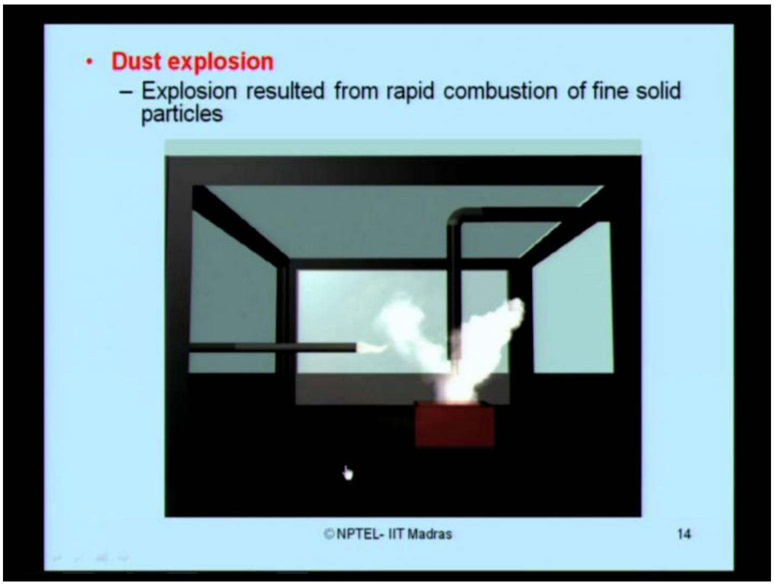

- **Dust explosion**
  - Explosion resulted from rapid combustion of fine solid particles

The next kind of explosion can also be caused due to the presence of dust; this is called as dust explosion. The explosion is resulted from a rapid combustion of fine solid particles there are fine solid particles that gets combusted and that result in an explosion. So, this is what we call as dust explosion.

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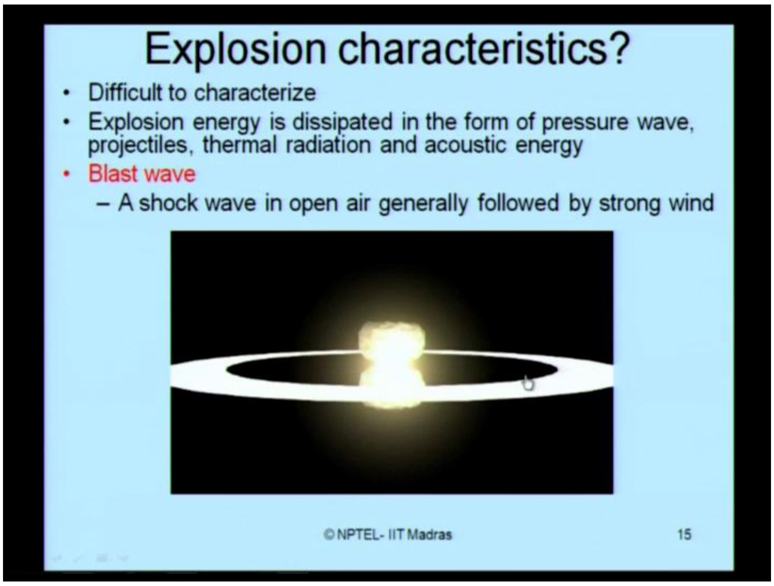

Explosion characteristics?

- Difficult to characterize
- Explosion energy is dissipated in the form of pressure wave, projectiles, thermal radiation and acoustic energy
- Blast wave
  - A shock wave in open air generally followed by strong wind

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The explosion characteristics are actually very difficult to characterize them. Explosion energy is actually dissipated in the form of a pressure wave, projectiles, thermal radiation and acoustic energy. In this context, it is very important to understand what do we define by a blast wave. Blast wave is actually a shock wave in an open air generally followed by a strong wind; basically it is a shock wave in an open air which is generally followed by a very strong wind blowing.

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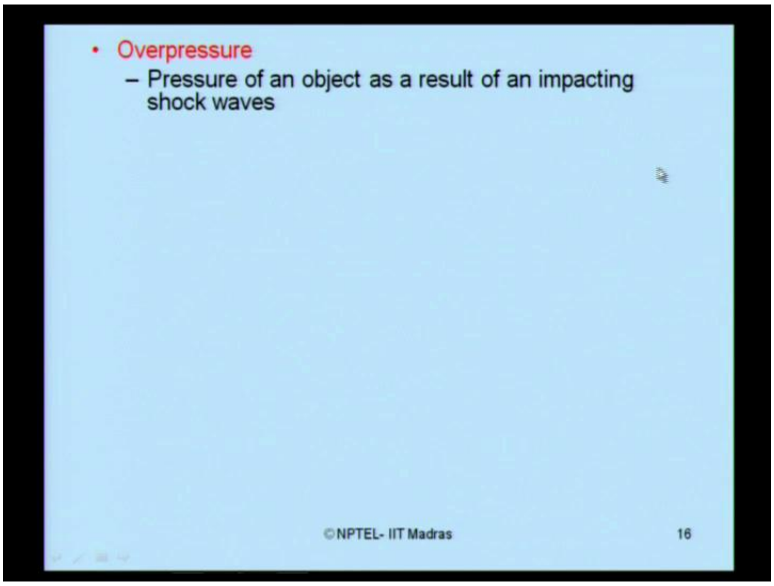

- Overpressure
  - Pressure of an object as a result of an impacting shock waves

What do we understand by overpressure? If the pressure of an object results from an impacting shock wave then we call that as an over pressure.

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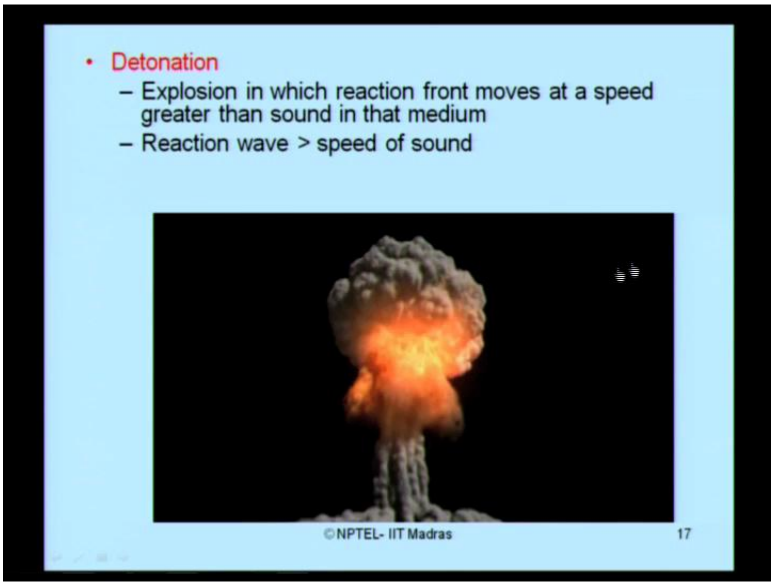

- Detonation
  - Explosion in which reaction front moves at a speed greater than sound in that medium
  - Reaction wave > speed of sound

Detonation is also called as an explosion in which reaction, front moves at a speed greater than sound in that medium. On the other hand, the reaction wave is much greater than the speed of sound. So, sound is heard later prior is the explosion. Such kinds of explosions are specifically termed in literature as detonation. Sound is heard later reaction comes first.

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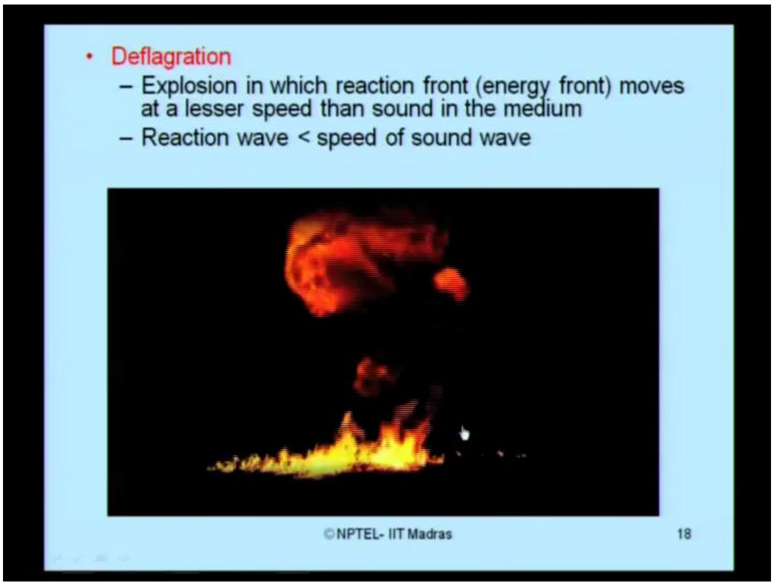

- Deflagration
  - Explosion in which reaction front (energy front) moves at a lesser speed than sound in the medium
  - Reaction wave < speed of sound wave

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There is another kind of explosion which is termed as deflagration in the literature. This is also a kind of explosion in which the reaction front moves at lesser speed than the sound in medium. On the other hand, the reaction wave is having a speed lesser than that of the speed of sound wave. So, first sound is heard then the reaction comes into play; this kind of explosion is what we call as deflagration.

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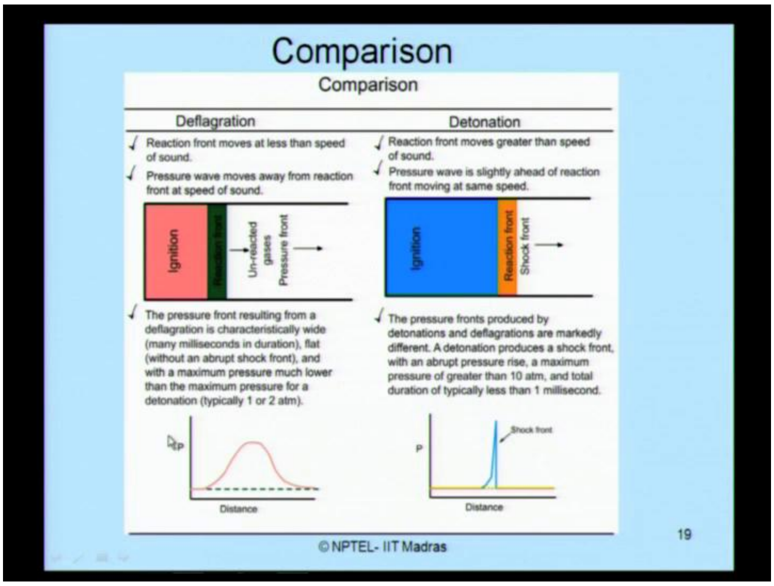

Comparison

Comparison

Deflagration	Detonation
✓ Reaction front moves at less than speed of sound. ✓ Pressure wave moves away from reaction front at speed of sound.	✓ Reaction front moves greater than speed of sound. ✓ Pressure wave is slightly ahead of reaction front moving at same speed.
✓ The pressure front resulting from a deflagration is characteristically wide (many milliseconds in duration), flat (without an abrupt shock front), and with a maximum pressure much lower than the maximum pressure for a detonation (typically 1 or 2 atm).	✓ The pressure fronts produced by detonations and deflagrations are markedly different. A detonation produces a shock front, with an abrupt pressure rise, a maximum pressure of greater than 10 atm, and total duration of typically less than 1 millisecond.

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Now, let us quickly see, how do we compare a deflagration with the detonation. In deflagration, the reaction front moves at a lesser speed than that of sound; whereas in detonation, the reaction front moves at a greater speed than that of sound. Here in, deflagration the pressure wave moves away from the reaction front at a speed of sound; whereas in detonation, the pressure wave is slightly ahead of reaction front moving at the same speed practically. The pressure wave front resulting from a deflagration is characteristically wide. So, it is a very wide phenomenon for a larger distance and with the maximum pressure much lower than the maximum pressure for a detonation. So, the maximum pressure what you get here is much lower than that of the maximum pressure what you get from a detonation; whereas detonation the pressure front produced by detonations and deflagrations are markedly different.

The detonation produces a shock front with an abrupt pressure rise and the maximum pressure of greater than 10 atmospheric, and total duration is very, very small; it may be practically 1 millisecond. So, detonation is an instantaneous process where the reaction front moves much faster than that of sound. So, you first see the explosion reaction then hear the sound where a very small duration; whereas in deflagration, hear the sound first then the explosion comes that is practically spread for a larger time duration. However, the pressure rise in detonation is much higher than compare to the pressure rise happening in the deflagration.

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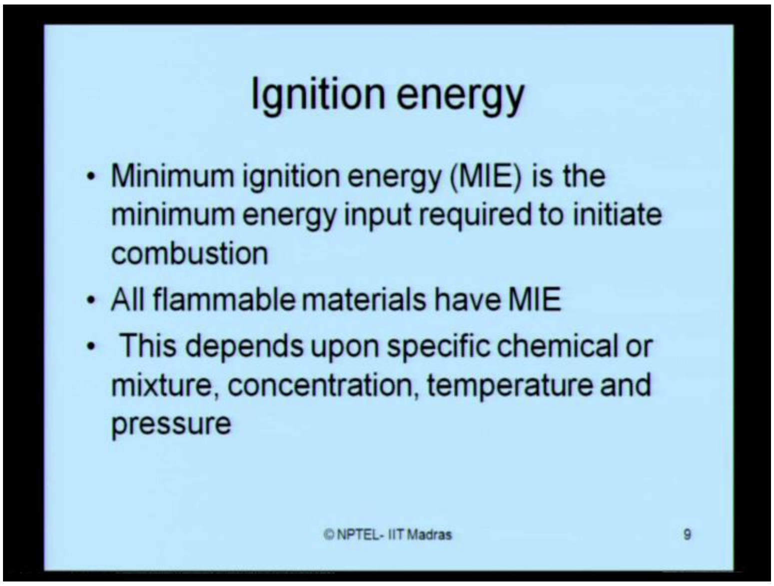

Ignition energy

- Minimum ignition energy (MIE) is the minimum energy input required to initiate combustion
- All flammable materials have MIE
- This depends upon specific chemical or mixture, concentration, temperature and pressure

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Now, let us try to understand something called ignition energy. It is nothing but the minimum energy input require to initiate combustion for a given fuel or a mixture. Any fuel or a mixture requires a minimum amount of ignition energy which is to be given as an input, to initiate the combustion process. Generally all flammable materials have a minimum ignition energy requirement, and this MIE value depends on specific chemical or the mixture of the chemical, when it is a mixture then the concentration of different components of the mixture, and of course, on the operating temperature and pressure of the mixture.

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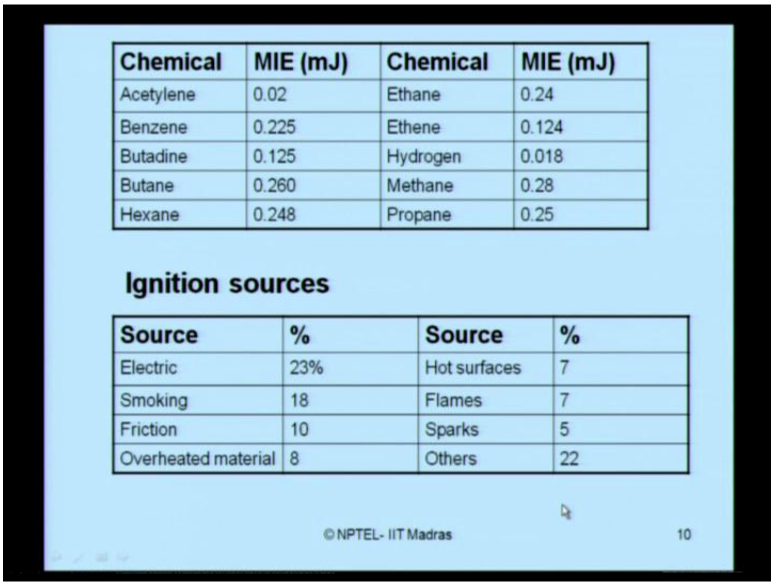

Chemical	MIE (mJ)	Chemical	MIE (mJ)
Acetylene	0.02	Ethane	0.24
Benzene	0.225	Ethene	0.124
Butadine	0.125	Hydrogen	0.018
Butane	0.260	Methane	0.28
Hexane	0.248	Propane	0.25

Ignition sources

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

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For different chemicals, for our understanding, I have already presented in a tabular form the MIE value in mJ. Acetylene, benzene, butadiene, butane, hexane; the values are given for different chemical in terms of MIE values. Then let us try to understand what will be the percentage contribution for ignition source from different sources.

So, if you take electric as an ignition source, generally the contribution for combustion or ignition is about 23 percent. We will look at smoking is about 18 percent. If we look at friction, which develops heat, which is also causing ignition, that is about 10 percent. If we already have an overheated material present in the scenario or process it may caused or it may contribute 8 percent. If you have any hot surfaces that may contribute 7 percent; flames can contribute 7 percent; sparks can contribute the 5 percent and others put together can contribute to 22 percent.

Thank you.