Chemical Process Safety
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Lecture 21 - Fire & Explosions: Introduction

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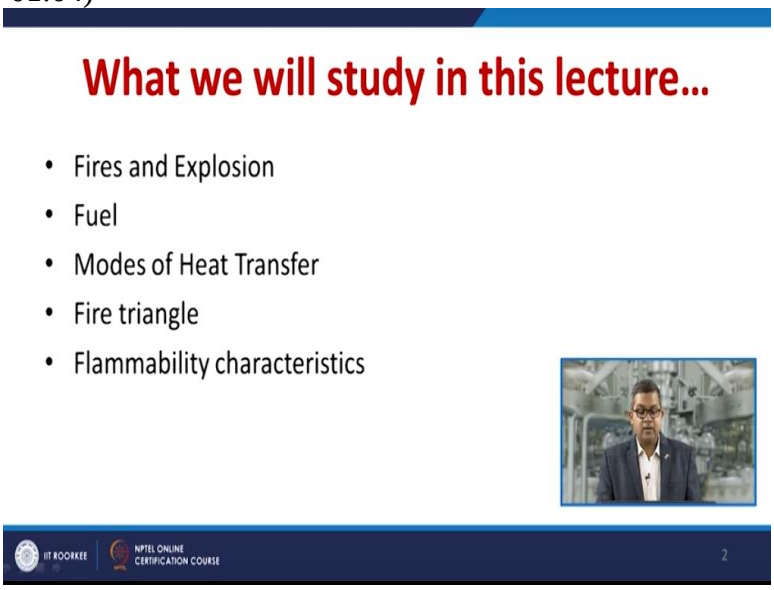

Welcome to this Fire and Explosion module and in this particular module, we are going to discuss about the fire and explosion, what are the basic definition of fire and explosion and what is the difference between the fire and explosion, what kind of and conditions required to produce any kind of fire, what how the heat being, whatever heat being generated in fire or explosion being transmitted to some other places, that is modes of heat transfer, we will discuss about the fire triangle, what are the necessary ingredients and what are the necessary arms of this fire triangle. We will discuss about the various kind of flammability characteristics.

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Now we know that fire is extremely dangerous not only for our domestic affairs but for the various industrial establishment. Now sometimes this fire may lead to explosion because explosion is the rapid generation of shockwaves, maybe because of fire, may or may not be because of some other reasons. So in this particular module, we will discuss that what are the different conditions required for the fire, how the fire may lead to the explosion, what kind of explosion are dangerous for the industrial establishments.

Because ultimately whenever there is a fire, then definitely there is a loss of not only to the human being but also for the vegetation, animal and above all the property. And sometimes explosion may lead to the hidden danger to the nearby buildings, to the vegetation, to the human being, etc. Now question arises what is fire? Now fire is very common, we cannot imagine our sustainability without fire, we cannot cook food, we cannot have several other aspects, we cannot steam etc.

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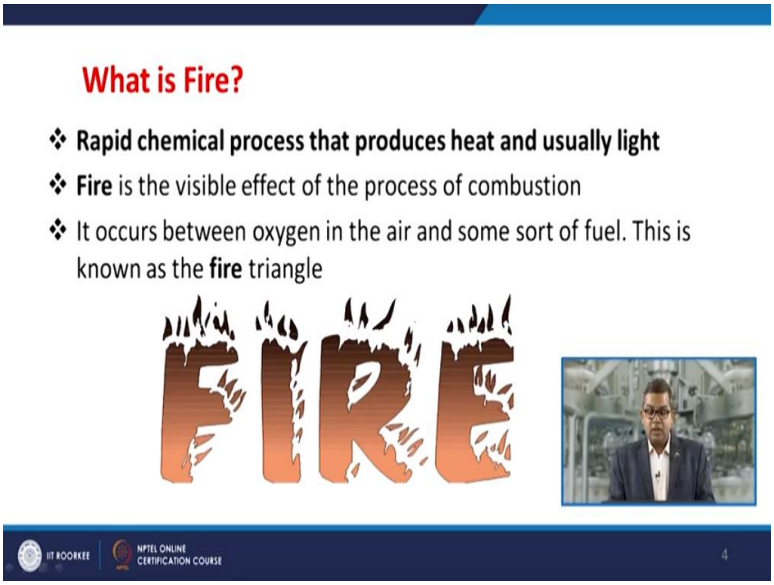

So what is fire? This is the rapid chemical process that produces heat and usually light, now fire is a visible effect of the process of combustion. Now for combustion what kind of different condition required, we will discuss in this particular module. Now it occurs between oxygen in the air and some sort of fuel, this is known as fire triangle.

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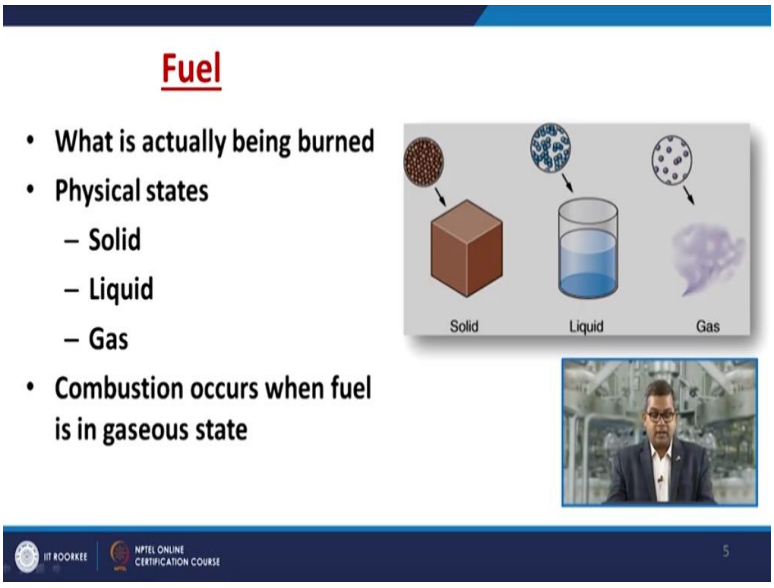

Now before we go into detail of this fire triangle, let us have a thing that what is fuel. Now fuel is that what is actually being burned because everything is not having the probability of fire generation ability. Now this fuel is available in 3 physical states: solid, liquid and the gases. Best

example of solid is coal; liquid, your gasoline; diesel gasesous, natural gas etc. So, combustion usually occurs when fuel presents in gaseous state.

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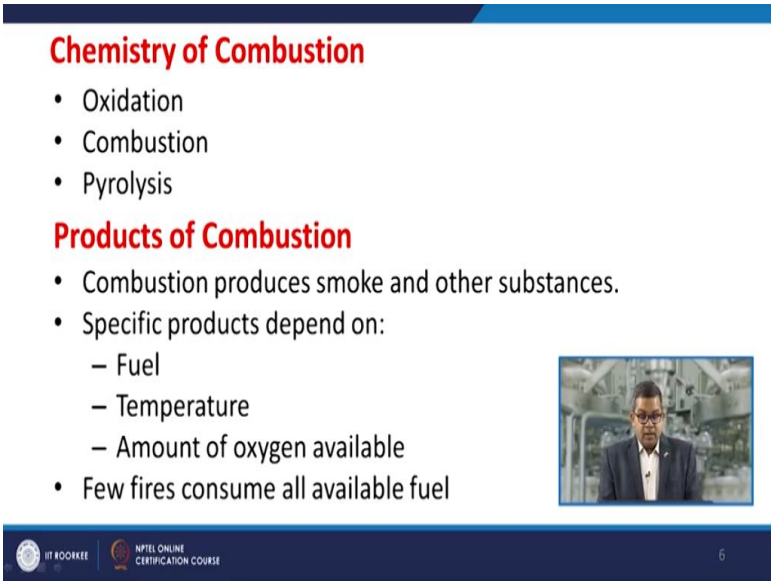

Now let us have a discussion about the chemistry of combustion, now usually oxygen and fuel they are having the affinity in 3 aspects. One is oxidation, another one is combustion, now if oxygen is not present then pyrolysis and usually whenever we discuss about fire then there are 2-3 major issues related to the sustainability of the fire. So if there is a net release of heat then only the fire will sustain. Now when there is a combustion then we can expect a variety of products for, of combustion. Usually, the combustion produces smoke and other substances, now this smoke sometimes carry some dangerous or toxic materials.

So specific products, whatever product being generated during the combustion, they are dependent on what kind of fuel being used and what is the temperature and how much quantity of oxygen is available for that particular process. Suppose, there are unsaturated hydrocarbon, then they may lead to the generation of CO_2, CO etc and how much fuel is being consumed during the process of fire. So, these all the product of combustion, they all depend on these three criteria or these three systems. Sometimes you may experience that few fires may consume all available fuels.

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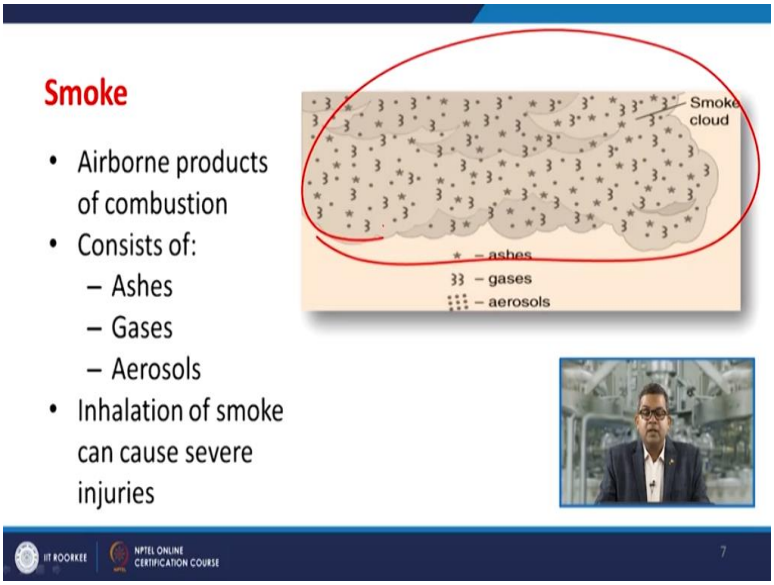

Now let us have a look of smoke, because usually when there is a fire then definitely you can expect the certain quantity of smoke being generated. Now, usually the smoke is airborne product of combustion, usually consists of ashes, some gases, some unburned hydrocarbon or some unburned fuel, different aerosols and usually these sometimes these ashes, gases or aerosols, they causes severe health hazards. So inhalation of smoke, they may cause severe illness, sometimes even it may lead to the death and usually the dangerous part is that generation of this type of smoke cloud, it may propagate to the to the nearby population where these ashes, the people may inhale the ashes, gases, aerosol etc, it may create the health hazard.

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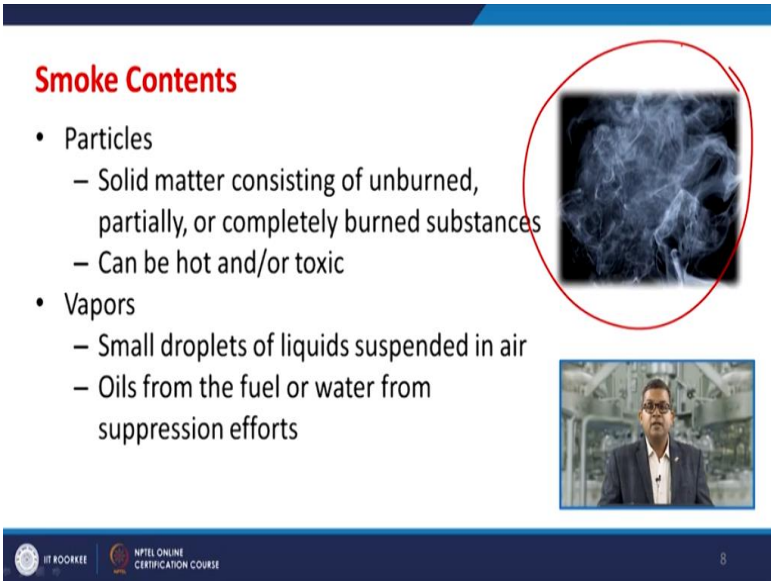

Now the smoke contents, they are usually particles, solid metal consisting of some unburned partially or completely burnt substances, it can be very hot or toxic in nature. Sometimes, certain vapors may be generated, they are the small droplets of liquid suspended. Oils from fuel or water from suppression efforts etc, again this type of effect is extremely dangerous.

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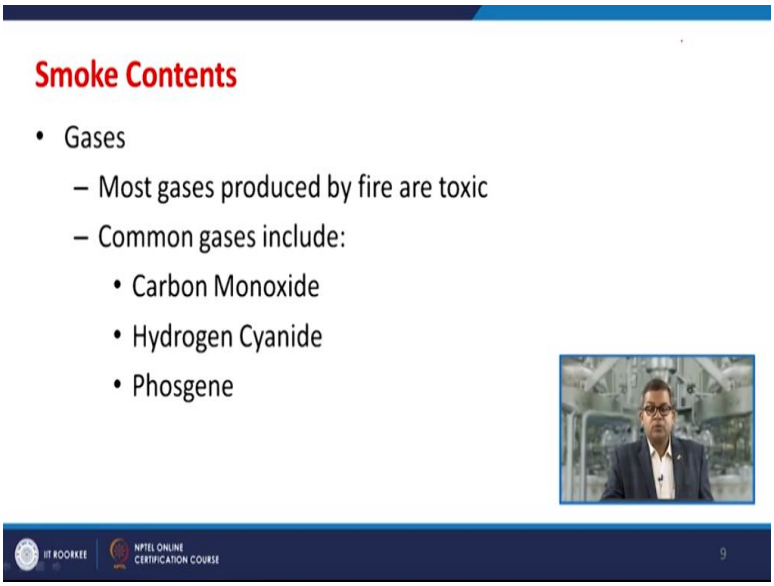

There may be a generation of certain gases, certain off gases and usually these gases produced by fire they are toxic in nature, CO, CO_2 and unburned hydrocarbons and sometimes if a polymer or a plastic product catches fire then some sort of dioxins, etc and these all gases are extremely

dangerous or extremely hazardous to the human being as well as they are the heat carriers. So, carbon sorry, common gases these usually includes the carbon monoxide, carbon dioxide, sometimes hydrogen cyanides, sometimes phosgene.

So these are so many accidents in past in the chemical industries they took place and they generated these off or dangerous gases and they become the part and parcel of human being and causes a severe death and a fatality to the human being. So, practically one must know that what kind of fuel, what kind of source of fuel is there and how the combustion took place so that the necessary action towards safeguard of mankind or towards the safeguard of environment can take in place.

Now, once we know that this chemistry of fire, then question arises, if this is an exothermic reaction and if the net heat being liberated during the course of fire then how it can be transmitted to some other place? In the Jaipur accident one particular storage tank caches the fire, caught fire and then the heat was transmitted to some other tanks and through the auto- ignition temperature all these tank, the temperature of those tank rose very rapidly, the vapors were formed and they took the temperature, they acquired a temperature of auto-ignition and then they catch the fire. So, we must know that what kind of different modes of heat transfer be there.

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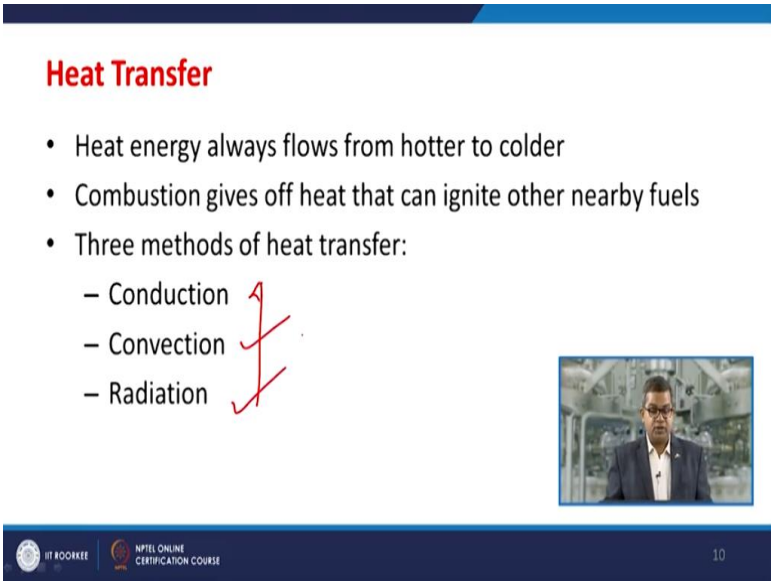

So heat energy, usually we know that this is a basic phenomenon that heat energy always flows from hotter to colder part. So combustion gives off heat that can ignite other nearby fuel, sometimes maybe because of auto-ignition and sometimes because of the conduction, because of

the convection or because of radiative heat transfer. So three methods of heat transfer use conduction, convection and radiation.

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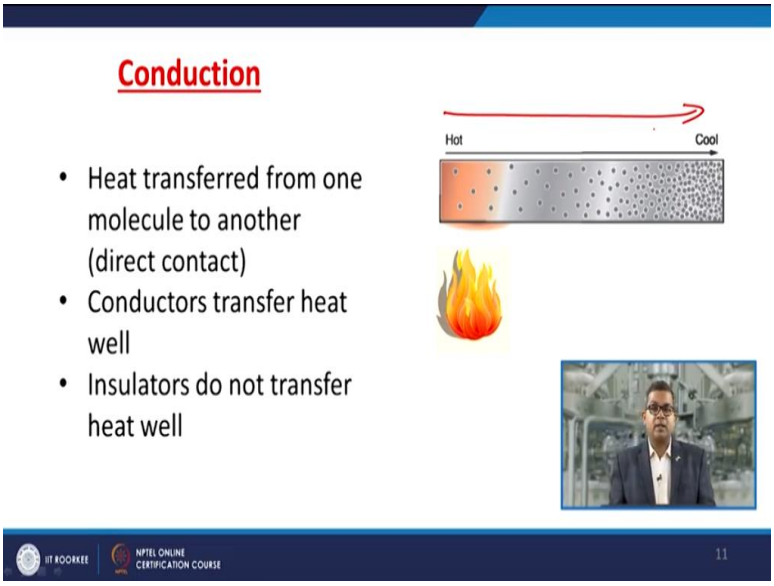

Now, let us have a brief look about these modes of heat transfer: Conduction, now heat transfer from one molecule to another, they are the direct in contact and the conductors usually transfer heat very well and you can experience that if you have a metal plate and if you try to heat one end of that particular metal plate, then automatically it goes to the other part of the metal plate. Now, usually to overcome such type of problem in a positive manner we usually adopt the concept of insulation and usually insulator do not transfer heat very well. So in case if you wish to inhibit the heat transfer so that it cannot go from one place to another, then you must use the insulators.

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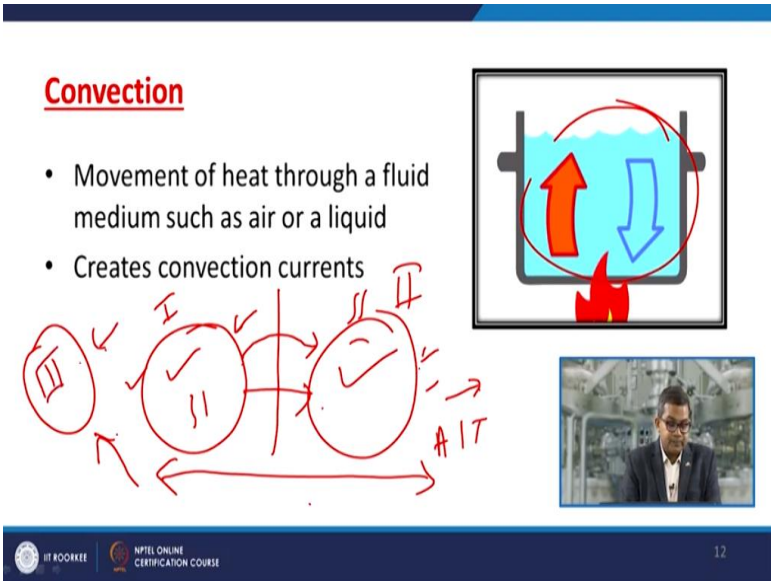

The convective heat transfer, the convection, movement of heat through a fluid medium such as air or liquid and usually they form the convective currents. You can see in this particular figure, they usually form the convective current and sometimes the heat may transfer from one place to another place through these convective layers.

Now let us have an example. Suppose, these 2 are the tanks where say petrol or a gasoline is filled and by any means this particular tank catches fire and because of the temperature rise, because of the other availability of oxygen in the near, in the air atmosphere the fire propagates and by this way lot of heat being generated in due course of time to this particular area. The generation of heat may lead to the formation of more and more vapors so that because oxygen is available in abundance, because it is surrounded by air then the fire catches rapidly and if it if it is having the heat value substantially high, then the heat may transfer to this particular tank number 2. This is tank number 1, this is tank number 2.

Now through this convective heat transfer the content of this particular tank is eaten up and it may produce enough vapor and if this particular tank is not equipped with safety devices or sometimes it may be equipped with the safety valve, so enough vapors may generated. And there are 2 possibility, one possibility is that this the fire which is here it may come to this place and the vapors being generated may catch the fire, another possibility is that the content of this particular tank may approach to the auto-ignition temperature so that it may ignite.

And you can imagine the scenario that both of the tanks may be in a position of burning and the quantum of heat being generated in due to course of time, so you need to think about that what should be the, how we can eliminate the formation of convective-convective heat transfer, how we can cordon it off once it is this particular tank catches fire, and if it is not possible then how we can control the fire, because if there is another tank then because the heat is propagated in such a way or heat is being liberated in such a way that both the tank they catches they catch fire, then the excess amount of heat may propagate the fire to this tank number 3. So, one must know that how to control this particular aspect.

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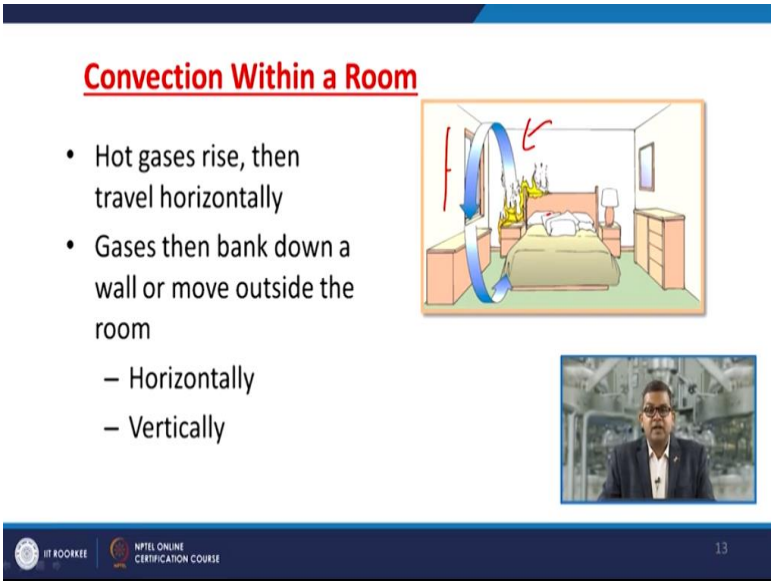

Sometimes when in our domestic affair there is a fire and that is unwanted fire then sometimes it may create like, suppose you are sleeping and you having a room heater or somebody ignited the cigarette and by any means the quilt or anything catches the fire and sometimes the convective layers may form within this room and these and the reason of the formation of these convective layers is that hot gases they are having the density difference with cold gases.

So there may be a chance of formation of this type of convective layers and these hot gases usually they travel horizontally. So gas then bank down a wall or move outside and sometimes horizontally or vertically etcetera. And whatever toxic gas is being generated, somebody who is within this room, the toxic gases those who are generated in due course of time that particular person may inhale this thing and it may create a future problem or it may create the immediate problem.

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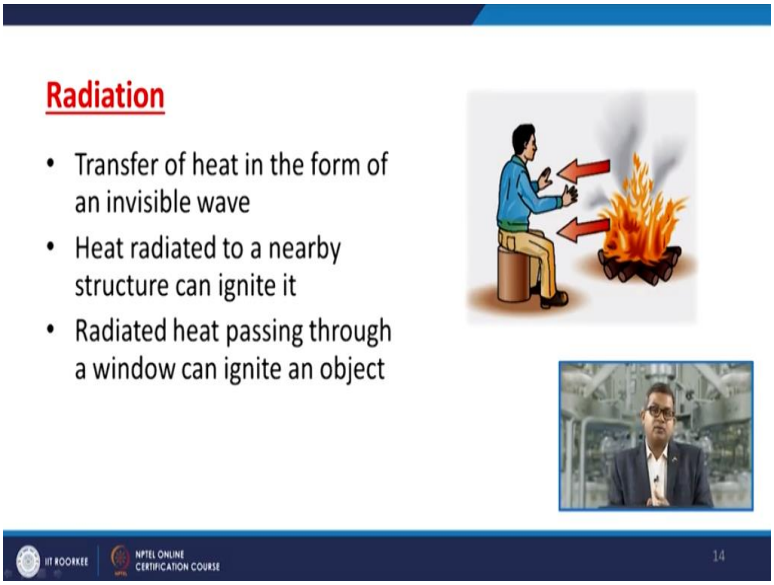

Radiation, the radiation is again a very good source of heat transfer and sometimes in past so many accidents are attributed to the radiative heat transfer. So the transfer of heat in the form of an invisible wave is clubbed under the head of radiation, so heat radiated to nearby structure even it can ignite it. Radiated heat passing through a window can ignite an object, so in combination of radiative heat transfer and convective heat transfer sometimes major accident they took place in passed.

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Now how we can prevent the accident there those who are attributed to fire? So a prima facie the engineers must know or must be familiar with that the fire and explosion properties of the material. It is quite obvious that if you are handling the petrol and if you are going to a petrol pump or petrol station, petrol filling station then always you took a proper attention or you have to take the proper attention not to ignite any kind of cigarette or sometimes there are so many advisories be written on those petrol pumps that not to do and do not's etc, because we all know that what are the flammable properties of petrol. Similarly, if you are working in a kitchen then you are familiar with the flammable properties of LPG.

So you cannot treat the petrol with simple potable water or simple water, so because we all know that it catches fire immediately and it produces off gases and the fire may propagate and fire may destroy each and everything. So, we usually take some precautionary measure. So when engineering perspective coming in the picture then engineers must be familiar with the fire and explosion properties of the material, that what is the boiling point, what is the flash point, what is the flame point, etc.

The nature of fire and explosion process, how it can catches the fire, what kind of things may lead to fire? Then, procedure to reduce fire and explosion hazard, if once it is ignited then, how we can reduce the fire? Sometimes, you may use the sprinkler system, sometimes you may you use to cordon off air, sometimes you may use to cut the fuel supply to the source, etcetera. So you must

know and all 3 things which we have covered in this particular aspect, they are particularly the engineered things and how we can engineer all those things we will discuss in next couple of slides.

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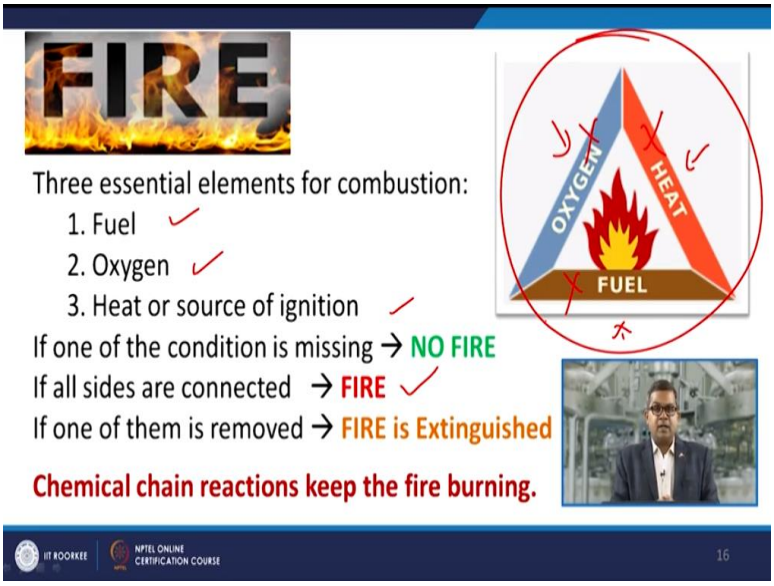

Now, to be more precise and to be more in scientific manner, the 3 essential elements are required for combustion or you can say fire: fuel, oxygen, heat or source of ignition.

So all 3 combine to form a fire triangle. Now if any one of the arm is missing then there would be no fire and if all the arms of this particular triangle are combined then there would be fire and suppose if you wish to extinguish the fire you need to eliminate any one of the arm. So usually whenever we remove oxygen or net release of heat or fuel supply then fire is extinguished, so usually in other aspect this is the chemical chain reaction which keeps the fire burning.

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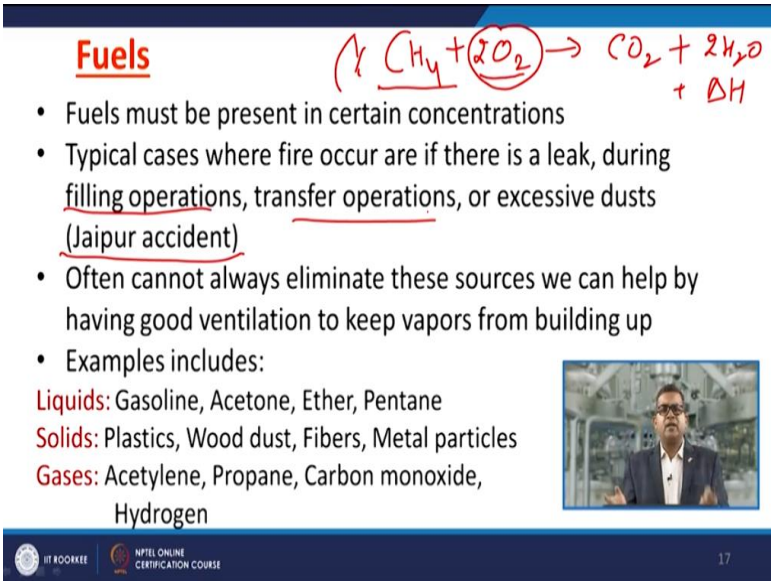

Now how we can assess that what are the necessary conditions for the formation of fire triangle? So, prima facie, first thing comes into our mind is the fuel because usually when we used to go to the petrol pump or when you used to go to the kitchen, our subconscious mind says that there is a presence of LPG, we do not bother about the source of ignition, we do not bother about the availability of oxygen at the source. So fuel, let us have a brief discussion about fuel, fuel must be present in certain concentration.

Now remember there is a stoichiometric metric demand of fuel, let us have a basic equation of methane burning, this is the basic equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \Delta H$$

Now for 1 mole of methane, the 2 moles of oxygen is required, so if the oxygen is available suppose in 2 mole and if there is a half mole, then this stoichiometric demand will not fulfill. So fuel must be present in a certain concentration, we will discuss about the lower flammability limit and upper flammability limit in due course of time.

Now typical cases where fire occur or if there is a leak during the filling operation, transfer operation or excessive dust, we will take up as a Jaipur accident as one of the case study and all aspects like filling operation, transfer operation they took place in the Jaipur accident, often we cannot always eliminate these sources. Sometimes it is very impractical to eliminate all things like

all arms of, or any one arm of fire triangle. Like if you wish to cook something in your kitchen, how can you imagine the scenario that your fire triangle is not fulfilled? You require the presence of fuel, you require the presence of oxygen, you require the presence of source of ignition and above all you require that net chemical chain reaction be there.

So we cannot always eliminate these sources. We can help by having the good ventilation or we can have help of good housekeeping to keep the vapors from building up. Now there are certain examples of liquid, solid and gaseous fuels like gasoline acetone, ether, pentane; they are clubbed under the head of liquid. Solid; plastic, wood, dust, fiber, metal particles, etc. Gaseous, acetylene, propane, carbon monoxide, hydrogen, etc. So you can list, you can enlist N number of source of fuels. So once you characterize the few, then the oxidizers.

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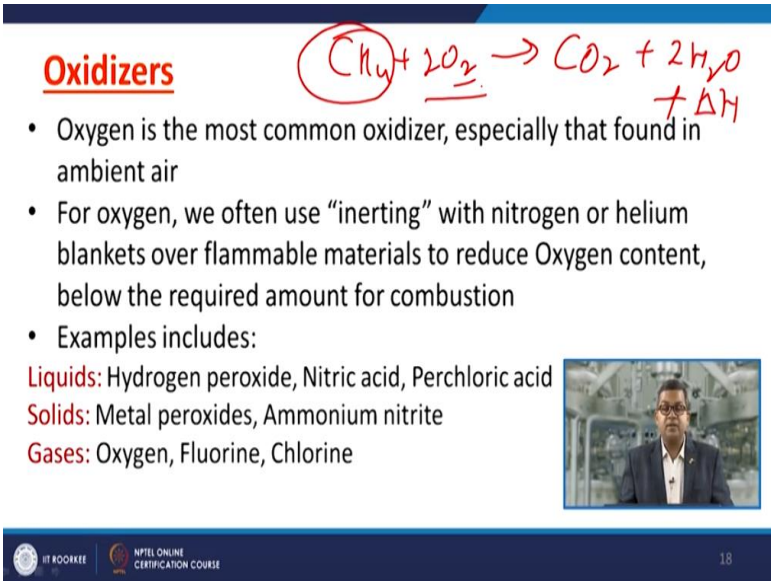

Oxygen is the most common oxidizer, especially that found in ambient air. So now why the oxygen or oxidizers are important? The reason is that, suppose if we wish to extinguish the fire and sometimes it is not possible to cordon off oxygen, then we should dilute the fuel concentration in such a way that the essential amount of oxygen whatever required as per the requirement of stoichiometric nature then the concentration should be on the lower side.

So for oxygen we often use inerting with the nitrogen or helium blankets over the flammable material to reduce the oxygen content or to cordon it off from the fire. So the oxygen content should be below the required amount of combustion. Go back to the previous example:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \Delta H$$

now if for 1 mole of CH4 if the oxygen is, suppose oxygen the availability of oxygen is say for 1 mole then definitely there would be no fire because the mixture is too lean to combust.

So it is essential that the oxygen must present in sufficient quantity whether you are taking the fire in a positive manner or you are taking the fire in a negative manner. So a different type of oxidizers available as on date, the liquid hydrogen peroxide, nitric acid, perchloric acid. There are certain solid oxidizers like metal peroxides, ammonium nitrite, etc. They are certain gases; obviously oxygen is most common source of oxidizer, then fluorine, chlorine, etc.

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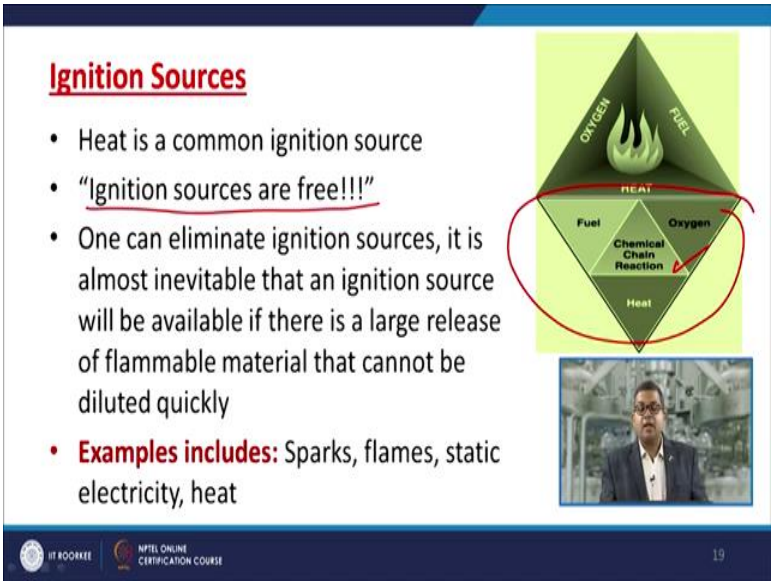

Then the last thing in the fire triangle is this ignition source, now usually heat is the common ignition source and remember one thing that all the ignition sources are free. Even the static charge being developed or accumulated on your hair may be dangerous and if you are wearing some silk cloths et cetera, sometimes you may observe that the static electricity being generated and sometimes you may observe that there is a generation of spark, it is extremely dangerous. The spark being produced by the shoe nails of your, nails of you shoes again it is easily or it is free available source of ignition.

Now one can eliminate ignition sources; it is almost inevitable that the ignition source it will be available if there is a large release of flammable material that cannot be diluted quickly. One more

thing is that whatever source of ignition you are using, it must have a sufficient quantity of energy or delta H within it so that it can ignite that combustible mixture. So once it is ignited then there is a formation of chemical chain reaction and the net release based on its delta H, it is sufficient to sustain that particular fire. So, the various example of ignition sources like a spark, flame, static electricity, heat etc. So, you can modify the fire triangle with respect to this chemical chain reaction because if you wish to sustain the fire then definitely you must have a chemical change reaction within it.

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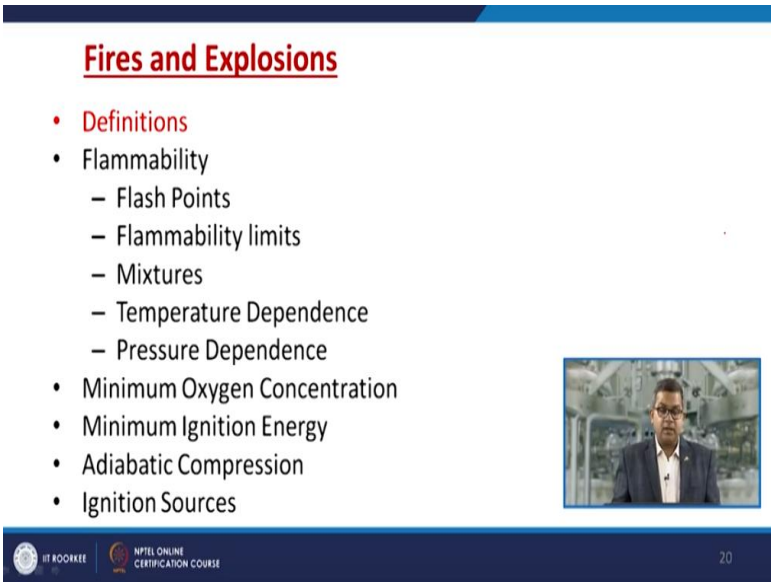

Now once we go into deeper in the fire and explosion, we must know the various definition because we will use different type of terminology in due course of time in all modules of this fire and explosion. So we have divided the things into a couple of aspect.

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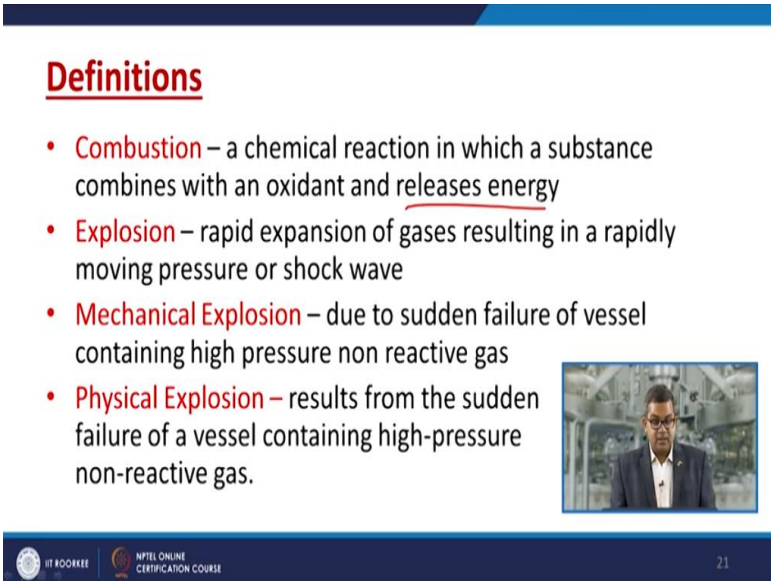

So first we will discuss about the various definition. The first scientific definition of combustion is the chemical reaction in which a substance combine with an oxidant and releases energy. Remember that particular release of energy is required for the sustainability of the fire, so if you remove this particular energy being liberated during the course of fire, you can extinguish the fire. Explosion, the rapid expansion of gases resulting in rapidly moving pressure or shockwaves. The mechanical explosion, this is due to the sudden failure of vessel containing high pressure non-reactive gases. There may be certain physical explosion, this results from the sudden failure of a vessel containing high pressure of non-reactive gases.

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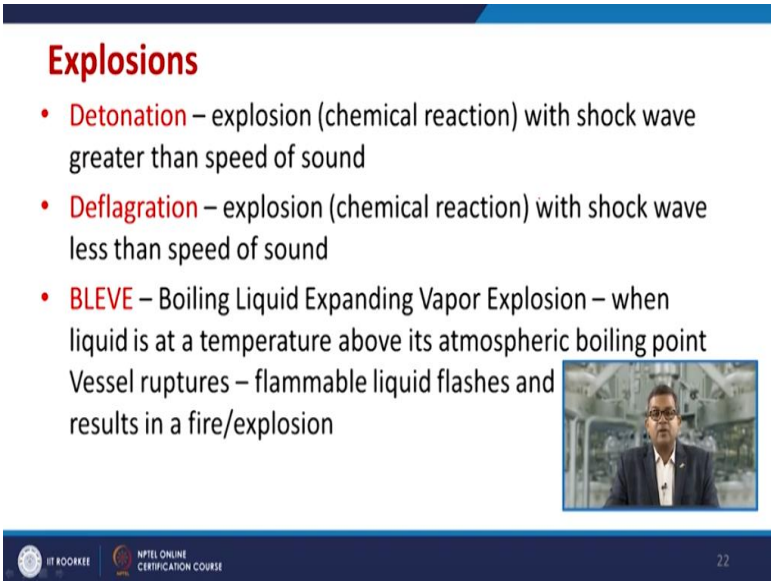

Then detonation, the explosion, we will discuss this detonation and deflagration in the subsequent modules. The detonation, explosion chemical reaction with a shockwave greater than speed of sound, this is extremely dangerous because sometimes the shockwave whatever being generated due to the explosion may match with the natural frequency of any object and a couple of times and that particular object may destroy or may collapse.

So this is the detonation is extremely important. Then, deflagration, the explosion or the chemical reaction with the shockwave less than the speed of sound. Then BLEVE, the Boiling Liquid Expanding Vapor Explosion, when liquid is at a temperature above its atmospheric boiling point sometimes vessel ruptures and flammable liquid flashes and results in fire or explosion. We will discuss this BLEVE in detail in the subsequent modules.

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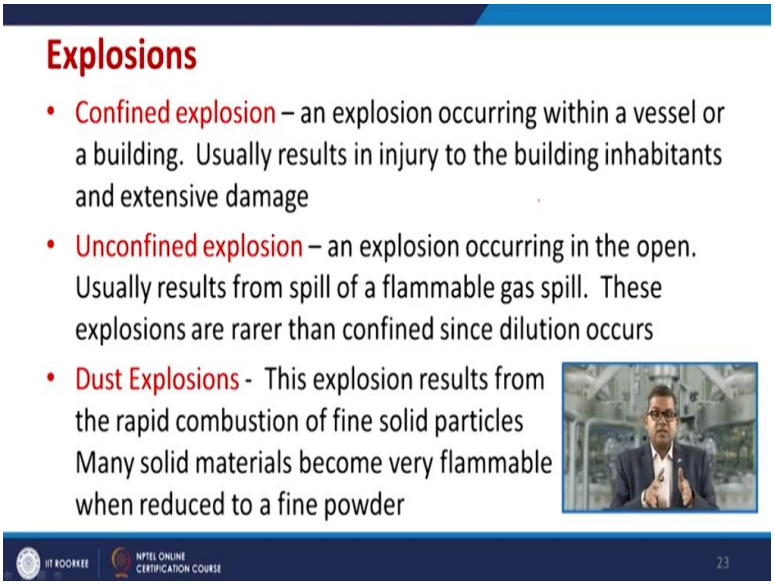

The confined explosions, then explosion occurring within a vessel or building usually results in injury to building inhabitants and extensively damage. The unconfined explosion and explosion occurring in open usually result from a spill of a flammable gas spill. These explosions are rarer than confined since dilution occurs.

Now, usually these unconfined explosions are extremely dangerous because you do not have any control and confined explosions, suppose you are sitting in a particular room and sometimes vessel (rupture) ruptures and the vapor cloud of the flammable vapor forms and it moves here and there in that particular room, then you are having the liberty or you are having some equipment or safety devices through which you can control that particular vapor cloud which is not, this facility is not available for the vapor cloud explosion, sorry unconfined explosion and in past the flibborough explosion and Jaipur accident they took place because of this unconfined explosion.

Dust explosion: Now this explosion results from the rapid combustion of fine solid particles and many solid material become very flammable when reduces to a fine powder. Another aspect is that since we learn about that detonation and deflagration, we must know that what is shockwave because we utilize the term shockwave over there.

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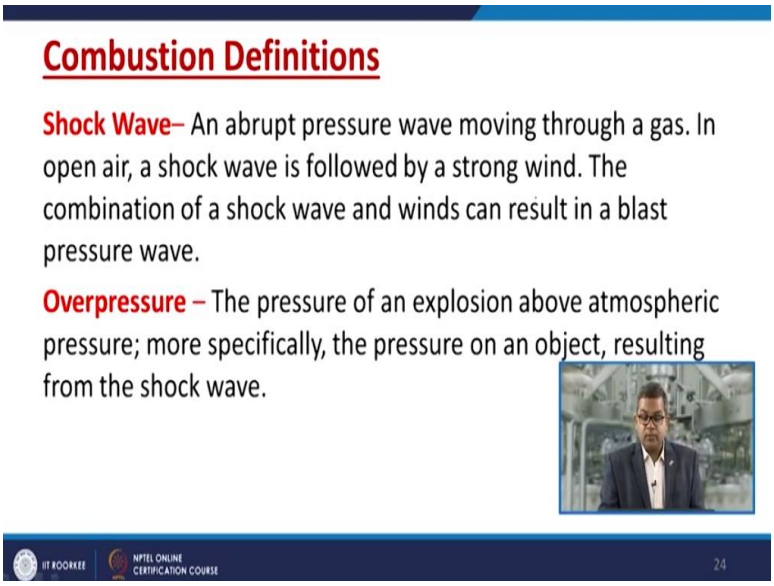

So shockwave, an abrupt pressure wave moving through a gas. And in open air a shockwave is followed by a strong wind. The combination of a shockwave and winds can result in a blast pressure wave. So you can see there is a combined effect of all factors. Overpressure, the pressure of an explosion above atmospheric pressure and more specifically the pressure on an object resulting from the shockwave.

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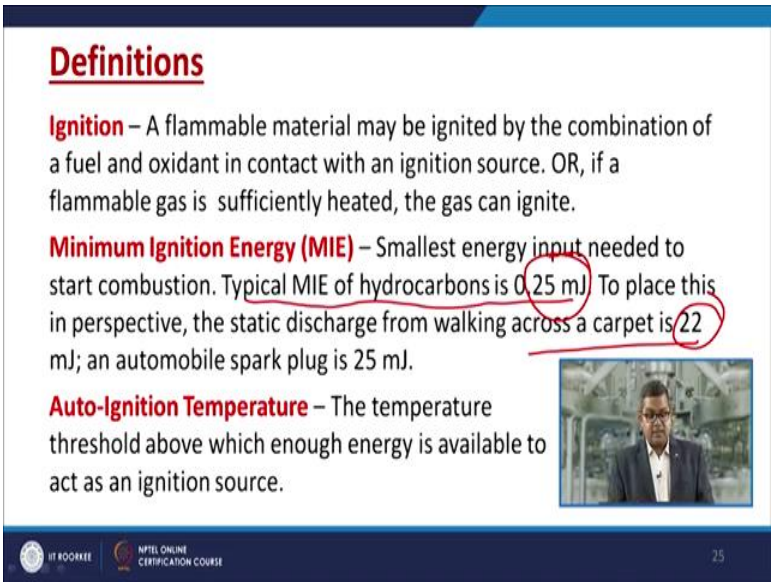

We should know about the ignition: Usually, a flammable material which may be ignited by the combination of a fuel and oxidant in contact with an ignition source or if a flammable gas is sufficiently heated the gas can ignite, so we must the practical definition of ignition. The minimum

ignition energy, the smallest energy input needed to start the combustion, so usually the typical minimum ignition energy of hydrocarbon is around 0.25 mega joule. Now to place this in perspective the static charge from walking across a carpet is 22 millijoule, an automobile spark plug is 25 millijoule.

Now you can imagine that this much amount of minimum ignition energy is required for combustion of hydrocarbon and walking across a carpet generates this much quantum of energy, so how dangerous it is? Auto-ignition temperature, the temperature threshold above which enough energy is available to act as an ignition source. So in this particular chapter we have discussed a particular module, we have discussed about the various definition, what is the chemistry of fire, what is the concept of a fire triangle because the knowledge of this fire triangle is extremely important to extinguish the fire.

In the subsequent modules, we will discuss about the flammability characteristics, what kind of definitions required, what are the flammability limits, how we can deal the mixtures, etc. Thank you very much.