Health, Safety and Environmental Management in Offshore and Petroleum Engineering

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Module - 03
Accident modeling, risk assessment and management
Lecture - 02
Flammability Characteristics

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Friends, let us continue with the second lecture in module 3, where we are going to talk about flammability characteristics. This is the second lecture on module 3, where we are talking focusing on risk assessment and management and accident model. We already said few characters are important for understanding the flammability characteristics better; one is what we call auto ignition temperature; other is what is called the flammability limits. Let us talk about the flammability characteristics in detail in which for most thing is the flammability limit. Flammability limit actually is a range of vapor concentration; it is a range, which could cause combustion in the presence of ignition source.

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Essentially, there are two limits; one is what we call upper flammability limit which is UFL; other is lower flammability limit, which is LFL. LFL actually is a limit below which the mixture will not burn. What could be the reason for this, the reason is the mixture is too lean, so it cannot cause ignition. Upper flammability limit is the limit above which the mixture will not catch fire; the reason is the mixture is too rich.

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So, an essentially flammability limit is actually the range between U F l and LFL because it is that region between which a mixture can catch fire. The next property could be interestingly limiting oxygen concentration; it is the minimum oxygen concentration, it is defined as the minimum oxygen concentration below which combustion is not possible. To activate combustion, we actually need minimum O 2 presence.

If the oxygen concentration is below a minimum required value, the mixture may not catch fire even in the presence of ignition source. Generally, this is expressed as volume percentage of oxygen; sometimes it is also called MOC that is minimum oxygen concentration. It is also called sometimes as maximum safe oxygen concentration, which is MSOC. So, LOC can be referred as MOC or MSOC it is actually the minimum oxygen concentration required or a mixture to catch fire.

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As we said earlier, the important consequence or effect of an explosion release is it can result in a shock wave, let see what is called as a shock wave. A shock wave is actually is an outcome of abrupt pressure wave is actually an abrupt pressure wave moving through a medium; interestingly a shock wave in an open air is followed by wind to activate the velocity this is called blast wave. The blast wave is the one which follows the shock wave which is activated by wind; one of the important vital characteristic of a shock wave is that one of the important characteristic is pressure increase in shock wave is so rapid that the process almost adiabatic.

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Thus, another important consequence which comes from explosion what we call as over pressure. Over pressure is nothing but an additional pressure imparted or an object by a shock wave, let us quickly see the consequence or the range of the flammability characteristics.

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Kindly pay attention to the figure shown on the screen now. The screen shows a graph, which plots temperature on x-axis and flammable vapor concentration on the y-axis. The red line indicates saturation vapor pressure curve; whereas a green and maroon indicates the lower flammability and upper flammability limits. Interestingly, as the temperature increases the upper flammability limit keeps on increasing and the lower flammability keep on decreasing from the original value and that increases the range of flammability because flammability is actually the range within which it can catch fire.

As the temperature increases, you will obviously see the range of a mixture which can catch fire is widened or increased. However, the gas or the liquid will remind nonflammable above upper flammable limit; and again on flammable below flammability limits. It is said that temperature which auto ignition is require it means the mixture will not require any external ignition source if catch fire, so it is that temperature which indicated as auto ignition. So, auto ignition completely lies within the flammable limits of any given mixture. We also have seen the flash point which is an important flammable characteristic of any given mixture, which has been now put together in all terms in a single graph as you can see from the curve now.

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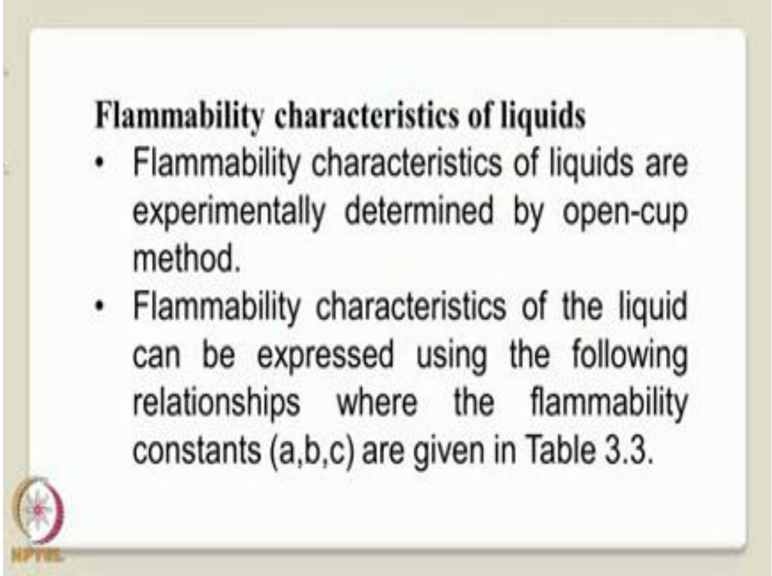

Let us talk about flammability liquids characters of liquids. The flammability characteristics of liquid or experimentally determined by a set up call open cup method, so they are generally determined experimentally by open cup method. However, the flammability characteristic of liquid can also be expressed using analytical relationship which you right now, if you know the constant a, b and c.

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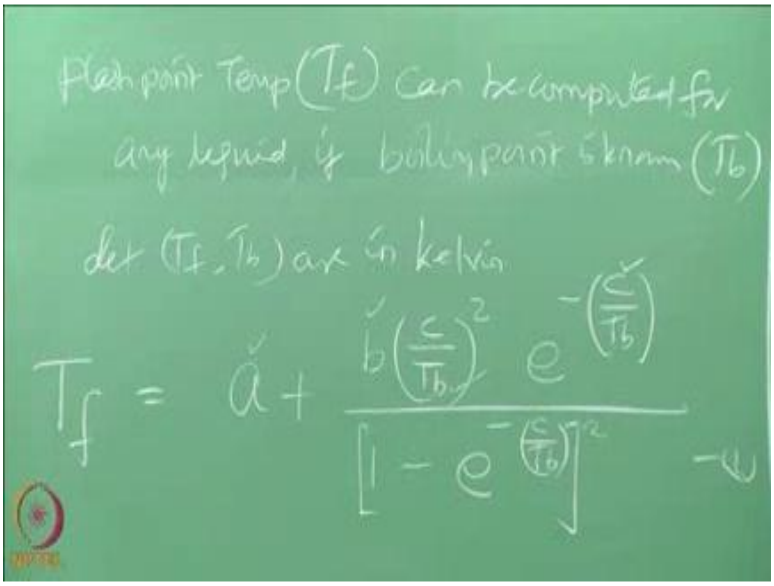

The flash point temperature T f can be computed for a given liquid for any liquid if the boiling point is known. Let us say both the temperatures are in Kelvin then flash point temperature of a liquid is simply given by a plus b into c by T b the boiling point exponential to the power of minus c by T b divided by 1 minus exponential to the power of minus c by T b the whole square equation 1. If I know the boiling point of the liquid, I can easily estimate the flash point if you know the constants a, b and c in the same particular equation. So, for different chemicals, these constants a, b and c which are used to estimate the flammability characteristics of a given liquid can be easily given and seen in the literature.

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CHEMICAL GROUP	a	b	c
HYDROCARBONS	225.1	537.6	2217
ALCOHOLS	225.8	390.5	1780
AMINES	222.4	416.6	1900
ACIDS	323.2	600.1	2970
ETHERS	275.9	700.0	2879
SULFUR	238.0	577.9	2297
ESTERS	260.5	449.2	2217
HALOGENS	262.1	414.0	2154
ALDEHYDES	264.5	293.0	1970

So, please pay attention to the table shown on the screen now, which gives me the values of these constants a, b and c for different chemical group as you see in the list here hydrocarbons, alcohols, amines and acids, ethers, sulfur, esters, halogens and aldehydes. So, the constants a, b and c are available substituting them and knowing the boiling point temperature of the liquid in Kelvin one can find the flash point temperature of the liquid in Kelvin again. And once you know the flash point one can easily find out the upper and lower flammability limits or characteristics using open cup method which can be easily estimated.

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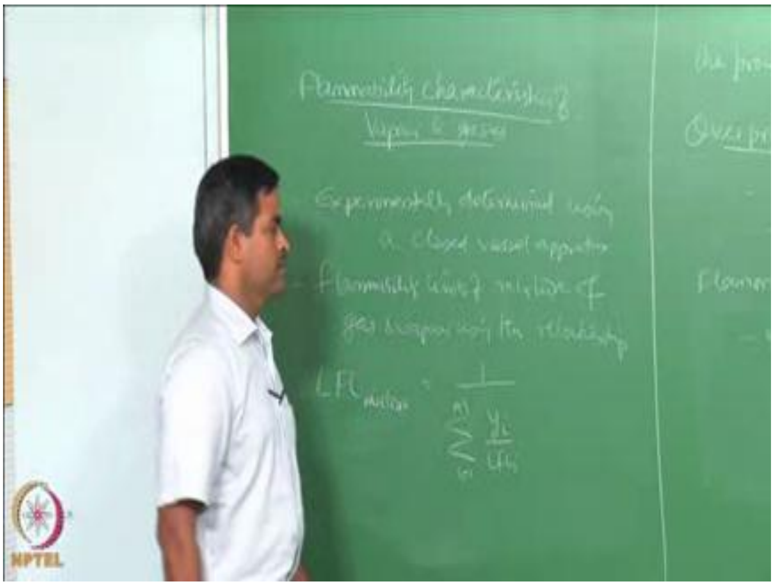

Let us talk about flammability characteristics of vapor and gases. Flammability limits of vapor can be also experimentally determined in a closed vessel apparatus. So, they can be experimentally determined using a closed vessel apparatus. Alternatively, one can also find the flammability limits of mixture of gas and vapor using the empirical relationship. So, the lower flammability limit of the mixture of the vapor and gas can be simply given by 1 by sum of y i by LFL of i and i is a sum here equation number 2.

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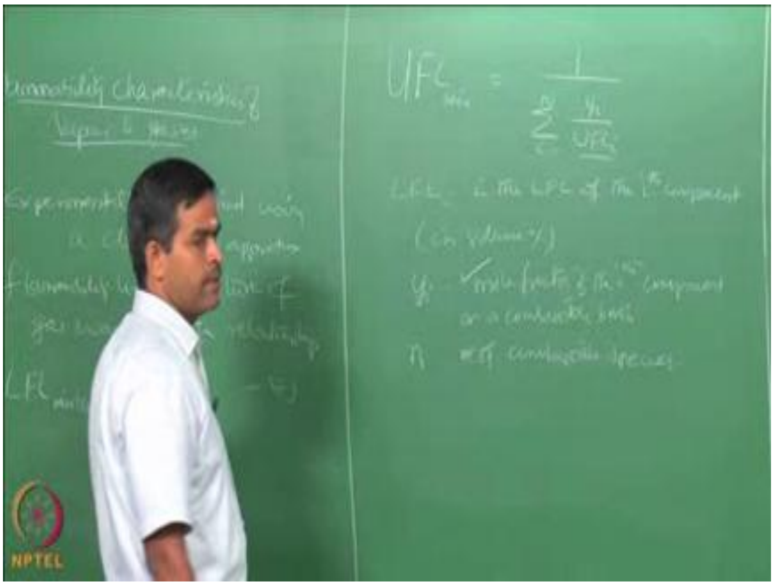

Upper flammability limit of the mixture can be again given by the same equation of course, substituted with y i by UFL of i, i varies from 1 to n, n is a number of gases or vapors considered for the analysis. So, LFL i is the LFL for the ith component is the lower flammability limit of the ith component in the mixture in terms of volume percentage; y i is actually the mole fraction of the ith component on a combustible basis; n is the number of combustible species which is considered for the summation. So, if you now the LFL and UFL of ith components present to the given system and if you know their mole fraction on the combustible basis one can easily find out the LFL and UFL of the complete mixture or the limits of a given mixture which is a given mixture of gas and vapor.

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Subsequently, the flammability limit behavior depends on both temperature and pressure. When the temperature increases, upper flammability increases while lower flammability decreases which makes flammable range of the fuel or the mixture more. So, increase in temperature will increases the flammable region more, so this increases the flammable region or a range one can say flammable range.

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So, coming to pressure, as pressure increases upper limit increases; whereas pressure has no significance on lower flammability limit at all; so no significance on the lower flammability limit. Therefore, the relationship of upper flammability limit with that a pressure can be given be simple equation. Upper flammability limit with that of pressure can be simply upper flammability limit plus 20.6 log p plus 1 where P is absolute pressure in let say mega Pascal. Interestingly, we have now agreed upon that estimate the flammability characteristics or probability of catching fire for a given mixture depends on the upper flammability ranges limiting oxygen concentration and auto ignition temperature, there are various characteristics based on which one can estimate what is the probability that a given mixture of gas or vapor or liquid can catch fire.

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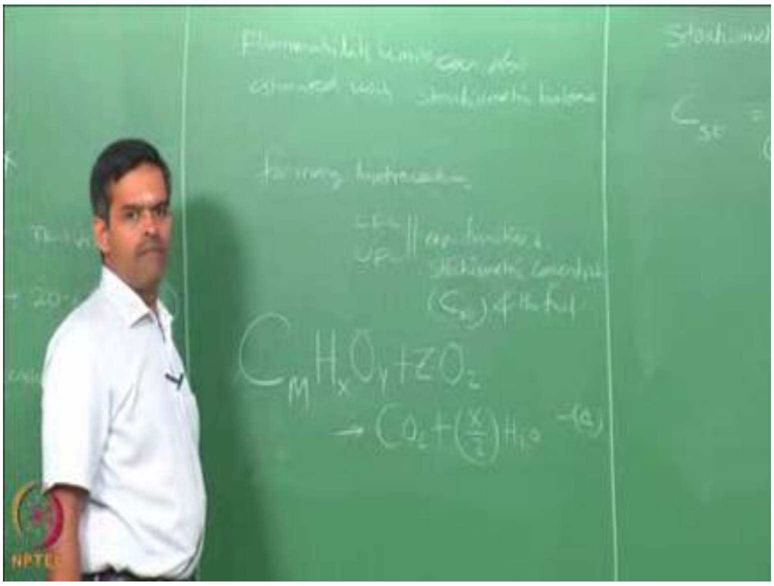

So, one can also estimate the flammability limits using stoichiometric balance; flammability limits can also be estimated using stoichiometric balance. Now, for many hydrocarbons in general the LFL and UFL, the lower flammability and upper flammability are essentially functions of stoichiometric concentration what we call as C st of the fuel. So, let us say general equation in which can be useful in computing this relationship let say C M hydrocarbon H with concentration X and oxygen with concentration Y plus oxygen concentration in terms of Z will give me carbon dioxide plus X by 2 concentration of Y that is a general stoichiometric relationship which indicating combustion reaction.

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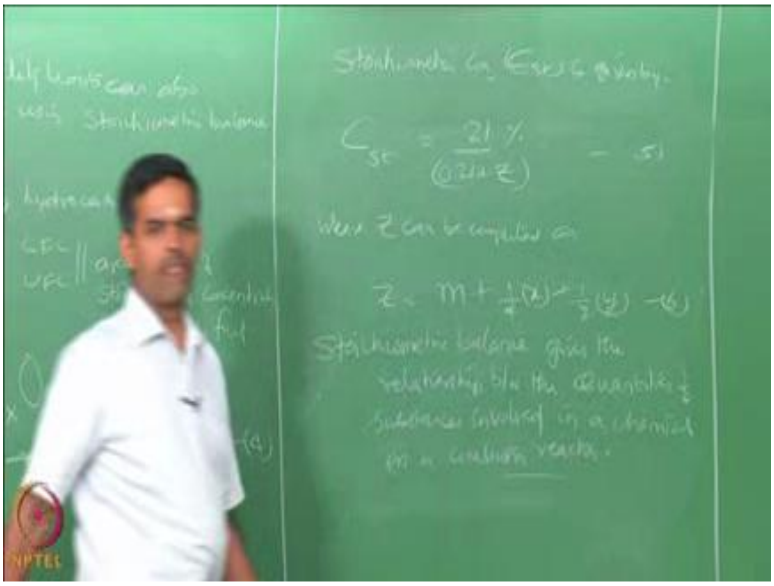

In that case the stoichiometric concentration which is given by 21 percent by 0.21 plus the z value. Z can be calculated, where z can be computed as z will be m plus one-fourth of x plus half of. We have something called stoichiometric balance. Stoichiometric balance gives the relationship between the quantities of substances involved the chemical combustion reaction stoichiometric balance gives the relationship between a quantities of substances involved in a chemical or a combustion reaction.

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This is a typically a ratio whole integers, this is the ratio of whole integers which includes the calculation of quantitative relationship of the reactance and the products of a balance chemical reaction. So, you need to have your balance chemical reaction. From the balance chemical reaction one can identify the quantitative relationships of the reactants and the products based on which one can easily find the stoichiometric concentration. Let say LFL the lower flammability limit can be given by 55 by 4.7 m plus 1.19 x minus 2.38 y plus 1. Whereas, the upper flammability limit can be given by 350 by 4.7 m plus 1.19 x minus 2.38 y plus 1 that is the equation number 7.

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Alternatively, flammability limits can also be computed using another equation. Alternatively LFL can be given by minus 3.42 by the delta H c plus 0.59 or 569 delta H c plus 0.0538 delta H c square plus 1.8. And upper flammability limit can be estimated as 6.30 delta H c plus 0.567 delta H c square plus 23.5 equation number 8. One can also estimate the limiting oxygen concentration LOC actually has units of percentage of moles of oxygen in the total moles. Actually, LOC is percentage of oxygen or let say percentage of moles of oxygen in the total moles. For hydrocarbons, LOC is actually estimated using stoichiometric relationship of the combustion reaction, which can be given by simply LOC, is approximately equal to z concentration of LFL it is equation number 8.

So, friends, in this lecture, we discussed about the flammability characteristics of liquid gas and vapor. We have understood what are the importance of lower flammability and upper flammability limits of a given mixture or a liquid. We want to see how these characteristics vary with respect to increase in temperature and increase in pressure. We have understood what is the range of flammability which we will actually responsible for understanding or estimating the probability of fire in a given situation when all the three arms of a fire triangle are inherently present in a process system. You also understood various methods and various empirical equations based on which the lower and upper flammability limits of liquid and vapor can be or mixture can be computed with different empirical relationships which we just now saw in the lecture.

In the next lecture we will discuss further more about the stoichiometric balance and how to estimate or how to actually draw a flammability diagram in detail if you know the properties of the flammability charecteristics of a given liquid or a mixture or hydrocarbons based upon stoichiometric balanced equation.

Thank you very much.