Chemical Process Safety
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Lecture - 13
Industrial Hygiene: Evaluation

Welcome to this module of industrial hygiene in which we will discuss about the evaluation technique, what kind of evaluation technique we have to encounter in industrial hygiene projects.

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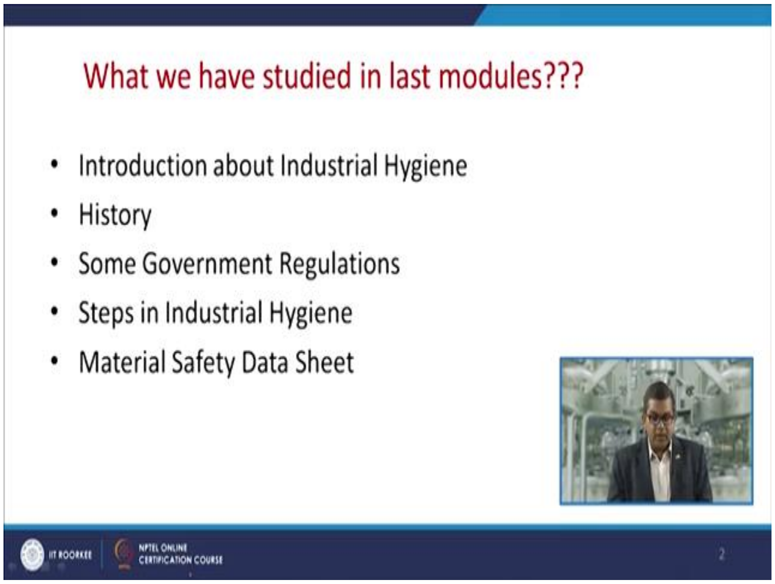

What we have studied in last modules???

- Introduction about Industrial Hygiene
- History
- Some Government Regulations
- Steps in Industrial Hygiene
- Material Safety Data Sheet

Now, up till now, we have studied about what is industrial hygiene, what is the history of industrial hygiene, there are some governmental regulatory abbreviations, what are the integral steps in industrial hygiene and Material Safety Data Sheet. So in the previous module we have discussed that what is MSDS and how do we identify the various toxicant or any kind of flammable vapors present at working place.

Now, evaluation, evaluation of toxic release is extremely important in industrial hygiene. The reason is that this tells you that up to how much level you can go for the safety devices because unnecessary putting up off the safety devices at workplace putting more system more and more complicated and creates another hazard. So, evaluation, this gives the quantitative mark of toxic substance present at your workplace, it tells you that beyond which your workers are overexposed, and so you need to put some safety measures for them.

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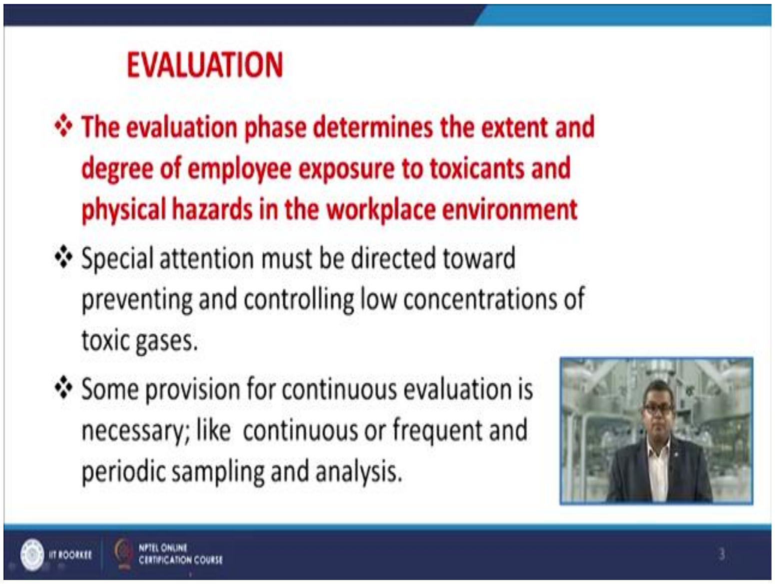

EVALUATION

- **The evaluation phase determines the extent and degree of employee exposure to toxicants and physical hazards in the workplace environment**
- Special attention must be directed toward preventing and controlling low concentrations of toxic gases.
- Some provision for continuous evaluation is necessary; like continuous or frequent and periodic sampling and analysis.

Now, the basic evaluation is that, this is the phase determines the extent and degree of employee exposure to toxicant and physical hazard in the workplace environment. Now, special attention must be directed towards preventing and controlling low concentration of toxic gases, we will discuss that how we can analyze those low concentration in due course of time. Some provision for continuous evaluation is necessary like continuous or frequent and periodic sampling and analysis.

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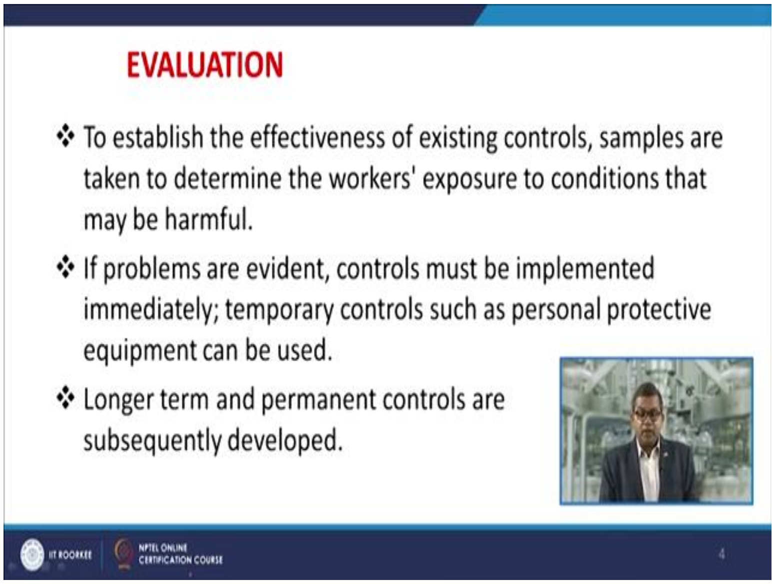

EVALUATION

- To establish the effectiveness of existing controls, samples are taken to determine the workers' exposure to conditions that may be harmful.
- If problems are evident, controls must be implemented immediately; temporary controls such as personal protective equipment can be used.
- Longer term and permanent controls are subsequently developed.

Now, to establish the effectiveness of existing control, samples are taking to determine the workers exposure to condition that may be harmful. So, in case the workers are under exposed, then there is no need to worry, but if they are overexposed, then you need to put some controlled measures, so that they are exposure towards the toxic substance may be eliminated.

Now if problems are evident, then control measures must be implemented immediately, temporary control such as the personal protective gear, it can be used as a first aid measures, longer term and permanent controls are subsequently developed.

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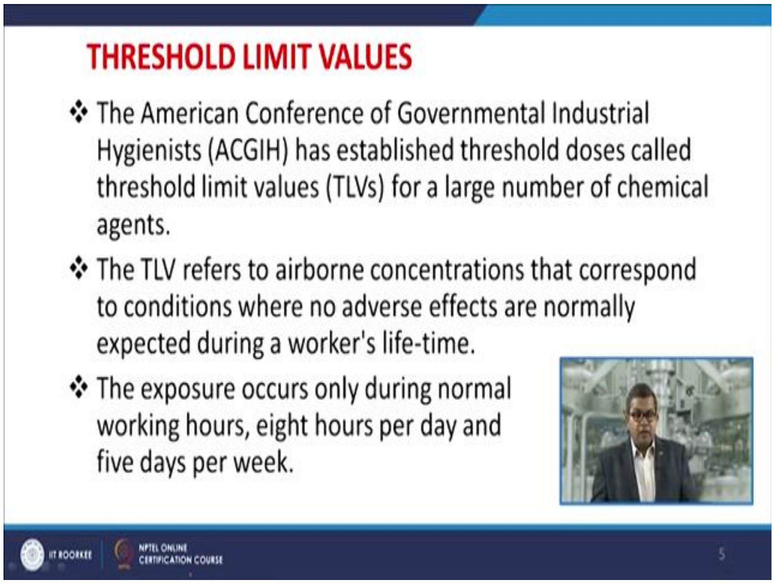

THRESHOLD LIMIT VALUES

- The American Conference of Governmental Industrial Hygienists (ACGIH) has established threshold doses called threshold limit values (TLVs) for a large number of chemical agents.
- The TLV refers to airborne concentrations that correspond to conditions where no adverse effects are normally expected during a worker's life-time.
- The exposure occurs only during normal working hours, eight hours per day and five days per week.

Now, based on the various samples, based on the identification tools, various governmental agencies they have set up the threshold limit values. The first hand threshold value was given by American Conference of Governmental Industrial Hygiene. They have established the threshold doses called a threshold limit value for a large number of chemical agents, this DLV refers to airborne concentration that correspond to condition where no adverse effects are normally expected during the workers lifetime.

Remember, the workers lifetime is almost 50 years as per the American Standard. The exposure occurs only during the normal working hours, usually 8 hours per day and 5 days per week.

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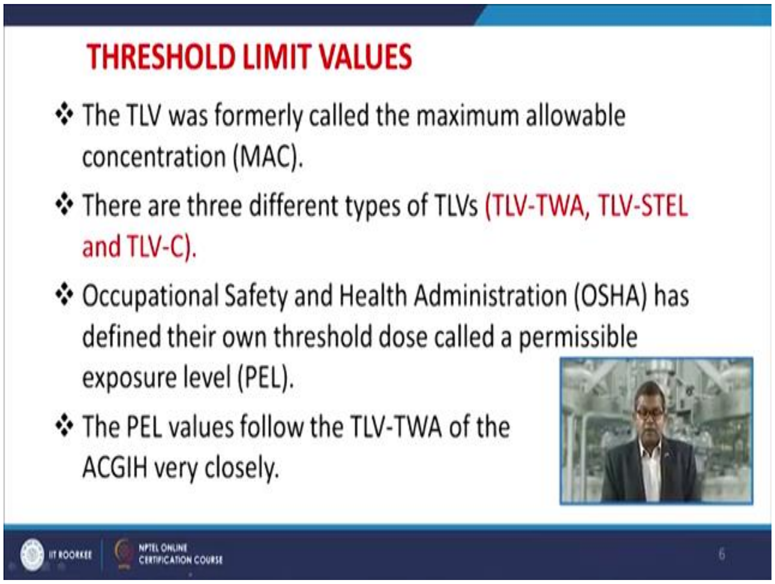

THRESHOLD LIMIT VALUES

- The TLV was formerly called the maximum allowable concentration (MAC).
- There are three different types of TLVs (TLV-TWA, TLV-STEL and TLV-C).
- Occupational Safety and Health Administration (OSHA) has defined their own threshold dose called a permissible exposure level (PEL).
- The PEL values follow the TLV-TWA of the ACGIH very closely.

Now, this TLV Threshold Limit Value for was formerly called the Maximum Allowable Concentration, that was below which the worker can easily work or worker can easily perform his or her normal duties. There are three different type of TLV’s TLV-TWA, TLV-STEL, STEL stands for short term exposure limit, TWA stands for time weighted average and TLV-C, C stands for ceiling.

Now Occupational Safety and Health Administration US based agency they has defined their own threshold doses called the permissible exposure level, these PEL values follow very closely to the TLV-TWA of ACGIH.

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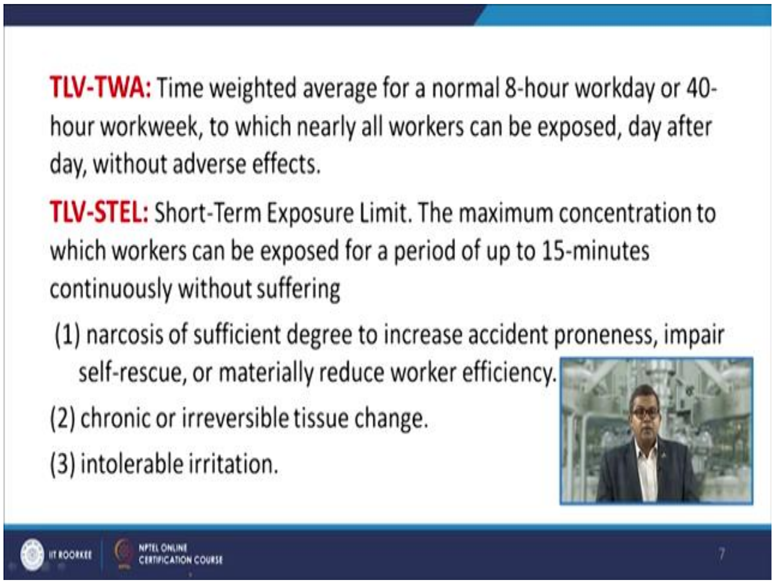

TLV-TWA: Time weighted average for a normal 8-hour workday or 40-hour workweek, to which nearly all workers can be exposed, day after day, without adverse effects.

TLV-STEL: Short-Term Exposure Limit. The maximum concentration to which workers can be exposed for a period of up to 15-minutes continuously without suffering

(1) narcosis of sufficient degree to increase accident proneness, impair self-rescue, or materially reduce worker efficiency.

(2) chronic or irreversible tissue change.

(3) intolerable irritation.

Now TLV-TWA, this is a time weighted average for normal 8 hour work day or 40 hours work week to which nearly all workers can be exposed day after day without adverse effect, that means below which you are safe, the TLV-STEL short term exposure limit which is the maximum concentration to the which worker can be exposed for a period up to 15 minutes, this is the limit beyond which the workers are overexposed.

Now, this continuously without suffering narcosis of sufficient degree to increase accident proneness, impair self-rescue or materially reduced to worker efficiency. Because ultimately when workers are over exposed either occupational illness or occupational injury, sometimes it may get fainted and they may, they may get over the police etc. So, they may get the occupational injury or sometimes fatality. So, ultimately, there is a challenge to the workers efficiency. The second aspect is the chronic or irreversible tissue changes, this is more drastic, then intolerable irritation.

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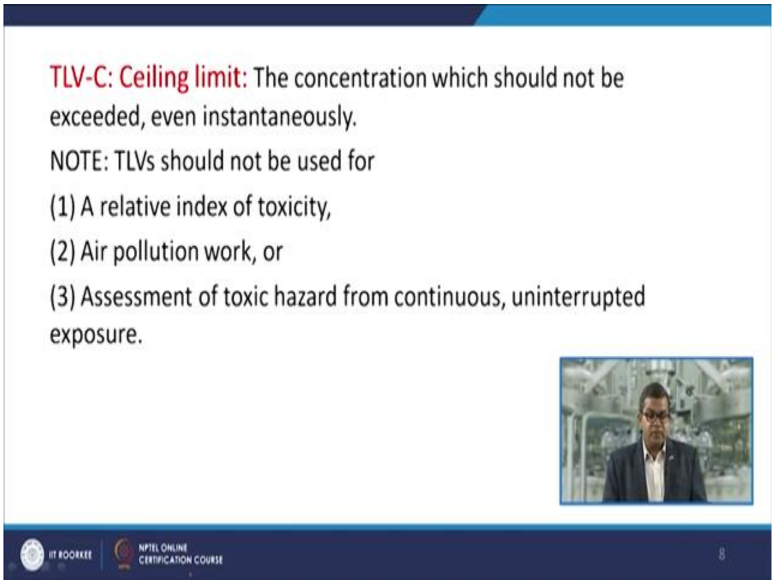

TLV-C: Ceiling limit: The concentration which should not be exceeded, even instantaneously.

NOTE: TLVs should not be used for

(1) A relative index of toxicity,

(2) Air pollution work, or

(3) Assessment of toxic hazard from continuous, uninterrupted exposure.

Now third one is that TLV-C or ceiling limit, the concentration which should not be exceeded even instantaneously beyond which some on toward accident may take place. Now, remember one thing should be noted that TLV should not be used for a relative index of toxicity. So, sometimes if you are having say fatality rate of say X based on the TLV then you cannot assume that every time when you work for a say Y stipulated hours, you cannot expect the fatality of X person.

So, it should not be used as a relative index of toxicity, it should not be used for air pollution work for that there are different standards, it should not be used for assessment of toxic hazard from continuous uninterrupted exposure because some other methodology can be used for their particular aspect.

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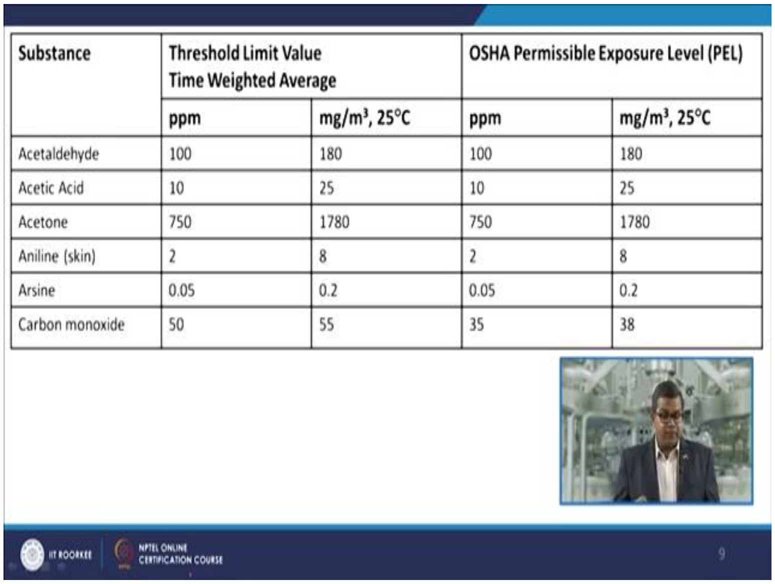

Substance	Threshold Limit Value Time Weighted Average		OSHA Permissible Exposure Level (PEL)	
	ppm	mg/m³, 25°C	ppm	mg/m³, 25°C
Acetaldehyde	100	180	100	180
Acetic Acid	10	25	10	25
Acetone	750	1780	750	1780
Aniline (skin)	2	8	2	8
Arsine	0.05	0.2	0.05	0.2
Carbon monoxide	50	55	35	38

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Now, here just for example, we have enlisted various substances and their threshold limit value and OSHA permissible exposure limit. Now two things must be remember, one is that what is the unit of these TWA and at what temperature they are reported and what is the unit like maybe sometimes in some other units etc ppm etc and if it is sometimes it is reported at say 30 degree Celsius, 35 degrees Celsius.

So, the standard is to report at 25 degrees Celsius, the standard is to report at milligram per meter cube and you can clearly observe that the threshold limit value they are in the closed proximation of OSHA permissible exposure limit. So, these values, the standard values are available in various handbooks.

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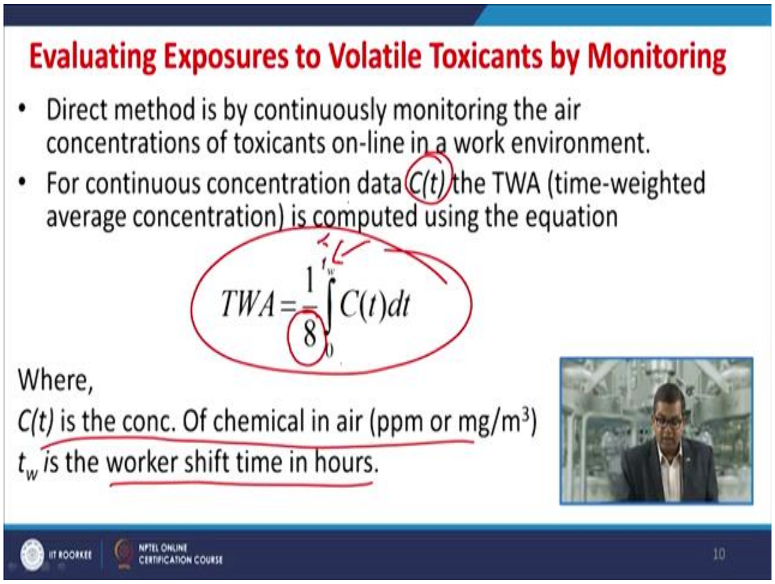

Evaluating Exposures to Volatile Toxicants by Monitoring

- Direct method is by continuously monitoring the air concentrations of toxicants on-line in a work environment.
- For continuous concentration data $C(t)$ the TWA (time-weighted average concentration) is computed using the equation

$$TWA = \frac{1}{8}\int_{0}^{t_w} C(t)\,dt$$

Where,

$C(t)$ is the conc. Of chemical in air (ppm or mg/m^3)

t_w is the worker shift time in hours.

Now, question arises that how we can evaluate the workers exposure to the volatile toxicant? Now, there are so many parameters and all parameters we need to discuss and we need to describe in this particular aspect. The one parameter is that up to how long it is exposed to the atmosphere, maybe no doubt the shift is of 8 hours, but sometimes the workers are working say 10 hours, 12 hours etc.

So, there are various tools available through which suppose I am working in this particular pool of any toxic substance. So, what is the concentration of that particular evaluation? Is the rate of evaluation is constant throughout? Sometimes I may go out and come back and sometimes I am working from this place and sometimes I am working from 5 to 6 meters apart.

So, every time you have to look into that what kind of concentration profile is, so first case is that this is a evaluating worker exposure to volatile toxicant by monitoring, this is a direct method is by continuously monitoring the air concentration of toxicant online in a work environment.

Now, for continuous concentration data the CT that is the concentration at particular time of the time weighted average concentration is computed using this particular equation,

$$TWA = \frac{1}{8}\int_0^{t_w} C(t)dt$$

t_w is the worker shift time in hours and,

C(t) is the concentration of chemical in air, ppm or milligram per meter cube. Now, see this is utilizing the concept of 8 hour work shift irrespective that how many times, how much time worker has devoted to the working place.

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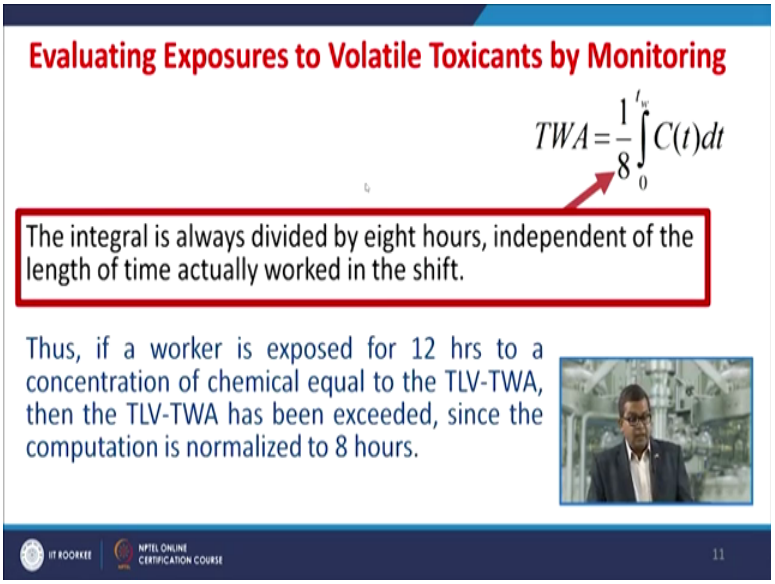

Evaluating Exposures to Volatile Toxicants by Monitoring

$$TWA = \frac{1}{8}\int_0^{t_w} C(t)dt$$

The integral is always divided by eight hours, independent of the length of time actually worked in the shift.

Thus, if a worker is exposed for 12 hrs to a concentration of chemical equal to the TLV-TWA, then the TLV-TWA has been exceeded, since the computation is normalized to 8 hours.

Now, this integral is always divided by this 8 hours independent of the length of the time actually worked. So thus, if worker is exposed to for 12 hours to a concentration of chemical equal to TLV-TWA than the TLV-TWA has been exceeded since the computation is normalized to 8 hours and necessary steps toward the safety of worker must be taken.

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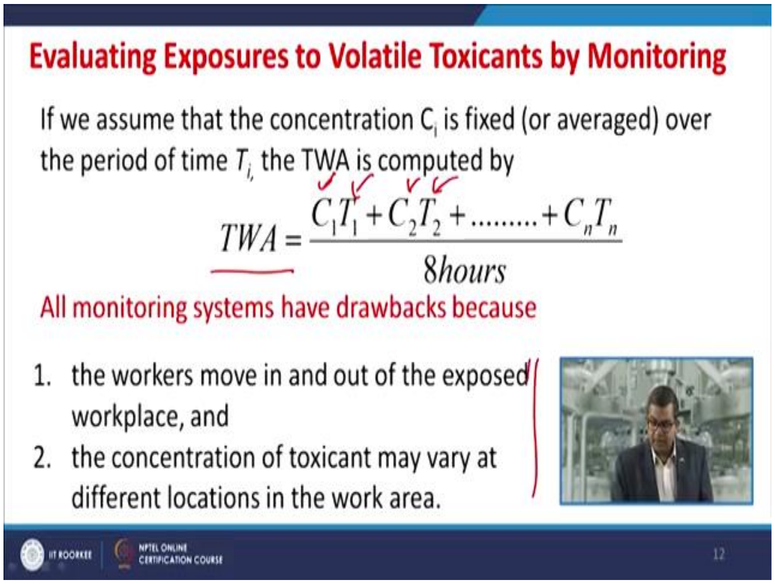

Evaluating Exposures to Volatile Toxicants by Monitoring

If we assume that the concentration C_i is fixed (or averaged) over the period of time T_i, the TWA is computed by

$$TWA = \frac{C_1T_1 + C_2T_2 + \ldots\ldots\ldots + C_nT_n}{8 hours}$$

All monitoring systems have drawbacks because

1. the workers move in and out of the exposed workplace, and
2. the concentration of toxicant may vary at different locations in the work area.

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Another aspect is that sometimes you are having a scenario where at the workplace that you may observe the different concentration of a particular component, sometimes the concentration is say C1 at this place and sometimes you move to that particular place where the concentration is C2 and sometimes you move to that particular place where the concentration is C3 up to there are N spots and apart from this you devote say you work for say a couple of hours over here where the concentration is C1, couple of hours at where the concentration is C2 and sometimes a couple of minutes you are working where the concentration is C3, so how we can analyze this particular scenario?

Remember we are using only one component, so if you assume that the concentration CI is fixed or average to over the period of time TI then usually TWA is computed with this formula:

$$TWA = \frac{C_1T_1 + \ C_2T_2 + \ldots\ldots\ldots + C_nT_n}{8\ hours}$$

So, this is again useful when workers move in and out of the exposed work place, suppose I am working here for 4 hours then I moved out for a lunch where the concentration is negligible, so we can eliminate that particular aspect, C2 equal to 0. The concentration of toxicant may vary at a different location in the work area. So, remember all the monitoring systems that have drawbacks because of this particular factor.

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Evaluating Exposures to Volatile Toxicants by Monitoring

- Safety personals play an important role in the selection and placement of workplace monitoring equipment and the interpretation of the data.
- If more than one chemical is present in the workplace one procedure is to assume that the effects of the toxicants are additive (unless other information to the contrary is available).

Now safety person, they play an important role in the selection of placement of workplace monitoring equipment and the interpretation of data. If more than one chemical is present in the workplace, one procedure is assumed that the effects of the toxicant are additive, unless other information of the contrary is available.

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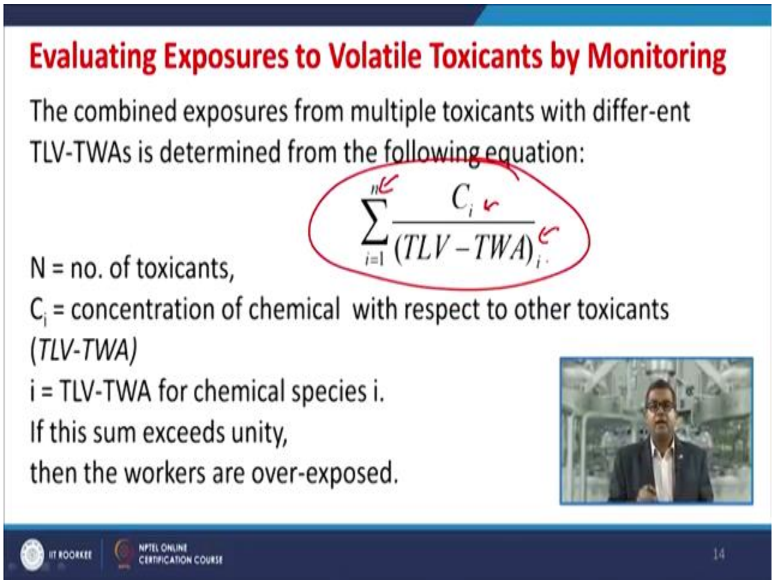

Evaluating Exposures to Volatile Toxicants by Monitoring

The combined exposures from multiple toxicants with differ-ent TLV-TWAs is determined from the following equation:

$$\boxed{\sum_{i=1}^{n} \frac{C_i}{(TLV-TWA)_i}}$$

N = no. of toxicants,

C_i = concentration of chemical with respect to other toxicants

(*TLV-TWA*)

i = TLV-TWA for chemical species i.

If this sum exceeds unity,

then the workers are over-exposed.

But sometimes we may deal with the N number of components out of which n minus X components may be toxicant and there may be a chance that their, their evaluation is constant. So, how we can evaluate the TWA or how we can analyze that my workers are overexposed or underexposed?

So, if they are exposed and we need to take the precautions, so this formula gives the liberty to calculate the total evaluation or total time weighted average of the workplace where the number of components are more than one, this is the combined exposure of multiple toxicants with a different TLV-TWA.

$$\sum_{i=1}^{n} \frac{C_i}{(TLV - TWA)_i}$$

Now here, n number of toxicants Ci is the concentration of the chemical with respect to other toxicant TLV-TWA, i is the TLV-TWA for the chemical species i.

Now if this sum exceeds unity, then the workers are overexposed and you need to take certain precautionary measures to overcome this problem. Sometimes, another scenario is that here we have taken an assumption that the concentration of ith component is constant throughout.

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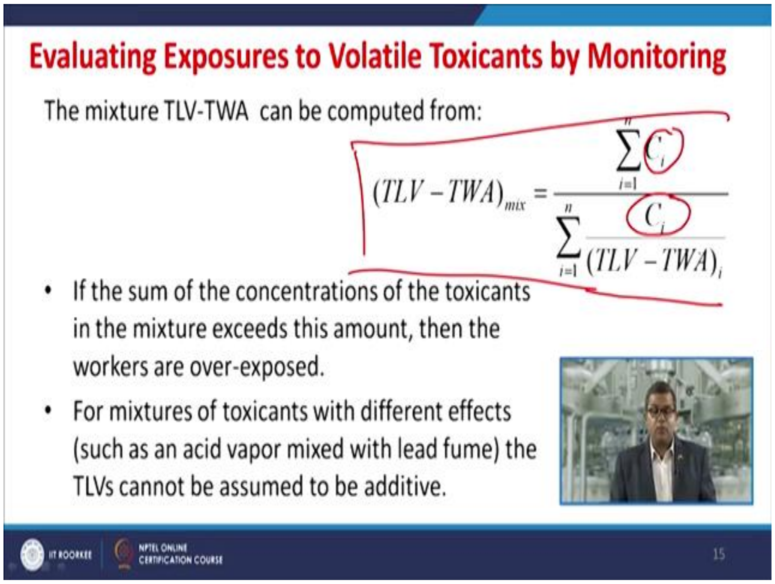

Evaluating Exposures to Volatile Toxicants by Monitoring

The mixture TLV-TWA can be computed from:

$$(TLV - TWA)_{mix} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \frac{C_i}{(TLV - TWA)_i}}$$

- If the sum of the concentrations of the toxicants in the mixture exceeds this amount, then the workers are over-exposed.
- For mixtures of toxicants with different effects (such as an acid vapor mixed with lead fume) the TLVs cannot be assumed to be additive.

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But sometimes you may, you may have a scenario where the concentration is also changing, concentration of different component is also changing, suppose I am working with say two component and both the components are having that different concentration that means their evaluation rate is on the different part. So, how we can calculate the TLV and TWA of the mixture? Because this gives you an idea that whether my workers are over expose or under exposed.

So, from handbooks you are having the standard TLV-TWA, you can easily monitor the concentration of individual component, so you utilize this particular formula:

$$(TLV - TWA)_{mix} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \frac{C_i}{(TLV-TWA)_i}}$$

Now, if the sum of the concentration of the toxicant in the mixture exceeds to this amount, then the workers are overexposed so need to take the precautionary measures, for mixture of toxicant with the different effects such as acid vapor mixed with the lead fumes, etc TLV cannot be assumed to be additive because you need to follow the separate protocol for them.

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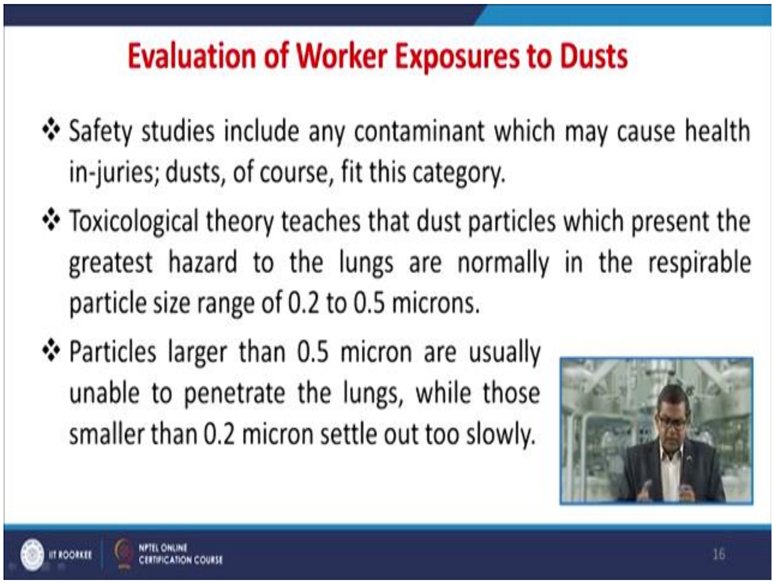

Evaluation of Worker Exposures to Dusts

- Safety studies include any contaminant which may cause health in-juries; dusts, of course, fit this category.
- Toxicological theory teaches that dust particles which present the greatest hazard to the lungs are normally in the respirable particle size range of 0.2 to 0.5 microns.
- Particles larger than 0.5 micron are usually unable to penetrate the lungs, while those smaller than 0.2 micron settle out too slowly.

Now, sometimes we may encounter the workers exposure to dust and dust is again very dangerous because asbestos dust or lead dust etc they may create the future health problem. So, safety studies this includes any contaminants which may cause health injuries, dust of course fit this category. Toxicological studies teaches that the dust particle which present in the greatest hazard to the lungs are normally in the respirable particle size range of 0.2 to 0.3 microns, remember nature has given us a natural filtering power like nose hair, mucus etc mucosal.

So, sometimes these small particles may get penetrated and they become the part and parcel of our respiratory system and it may accumulate to the lungs and they may create the future problem. So, we need to be aware about this dust problem. So, particles larger than 0.5 microns are usually unable to penetrate the lungs while those smaller than 0.2 microns settle out too slowly.

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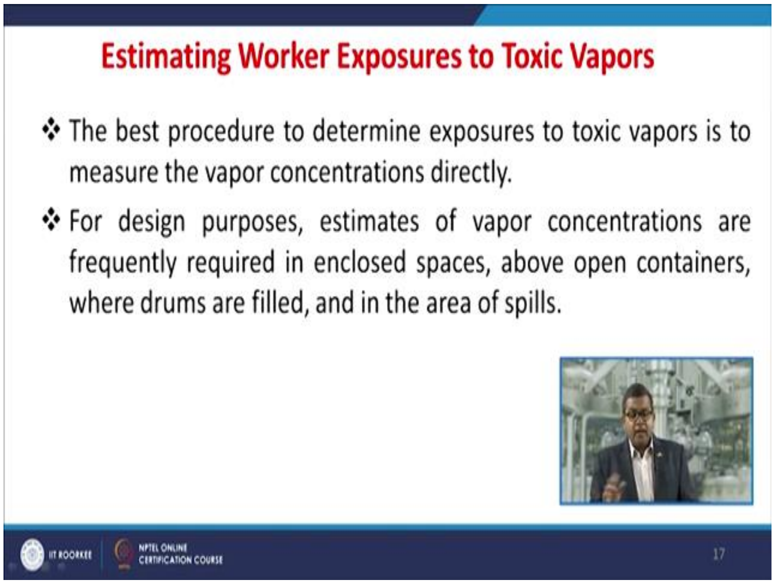

Estimating Worker Exposures to Toxic Vapors

- The best procedure to determine exposures to toxic vapors is to measure the vapor concentrations directly.
- For design purposes, estimates of vapor concentrations are frequently required in enclosed spaces, above open containers, where drums are filled, and in the area of spills.

Now again come back to estimation of worker exposure by the toxic vapor, the best procedure to determine the exposure of toxic vapor because sometimes the mist may create a problem. So, the best procedure to determine the exposures to toxic vapor is to measure the vapor concentration directly. For design purpose, estimate the vapor concentration, they are frequently required in enclosed space above the open container, where drums are filled in the area of spill.

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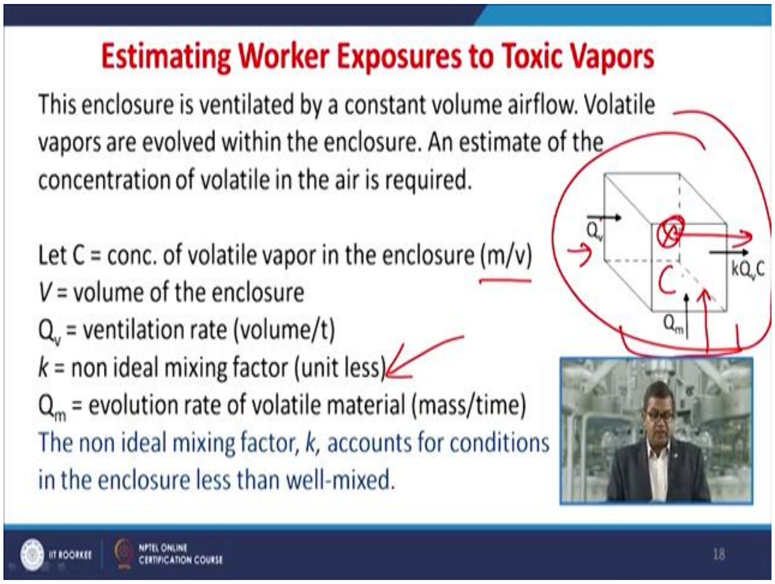

Estimating Worker Exposures to Toxic Vapors

This enclosure is ventilated by a constant volume airflow. Volatile vapors are evolved within the enclosure. An estimate of the concentration of volatile in the air is required.

Let C = conc. of volatile vapor in the enclosure (m/v)

V = volume of the enclosure

Q_v = ventilation rate (volume/t)

k = non ideal mixing factor (unit less)

Q_m = evolution rate of volatile material (mass/time)

The non ideal mixing factor, k, accounts for conditions in the enclosure less than well-mixed.

Now, this is the best example suppose I am working in this pool of toxic substance. Now, there are 2, 3 things which one should know that how the our system works. One is that what is the rate of evaluation of that particular toxic substance? Again, it depends on various parameters like molecular weight of that substance, what is the working temperature, what is the pressure, how much area is exposed to the atmosphere?

The second thing is that what is the rate of ventilation? Because ultimately suppose this is the working place and certain quantities evaluated and from my right, the certain ventilating air is passing through, now this ventilating air is mixing with that toxic substance. So, you must know as per the mass transfer theory, you must know that what is the mass transfer coefficient? What is the mixing constant? So you must know all these things and then through this ventilating duct it passes through the atmosphere or scrubbing column etc.

So, you need to find out the combined effect both in terms of evaluation, because again, do not forget that evaluation is dependent on various parameters and what is the rate of ventilation and what is the combined effect. So, how we can solve this particular aspect? So, for this the best thing is that take a cube, imaginary cube and this you assume that this enclosure or a cube is ventilated by constant volume of airflow.

Now here, there is a continuous evaluation of a toxic substance from this pool. Now, this is this, this is mixed at this enclosure and goes to the some either treatment device or scrubbing device or it is exhausted to the atmosphere. So, this enclosure is ventilated by the constant volume airflow, remember this is purely an assumption and volatile vapors are evolved within the enclosure. So, an estimate of the concentration of volatile in the air is required.

Now, let us see, let C is the concentration of volatile vapors in the enclosure unit is m by v, v is the volume of this particular enclosure and sometimes if you have other thing constant then you can integrate throughout,

Q_V is the ventilation rate in volume per time,

k is the non-ideal mixing factor that is usually unit less based on the master transfer theory,

Q_m is the evaluation rate of volatile material in mass per time.

Usually the non-ideal mixing factor k accounts for the condition in the enclosure less than well mixed.

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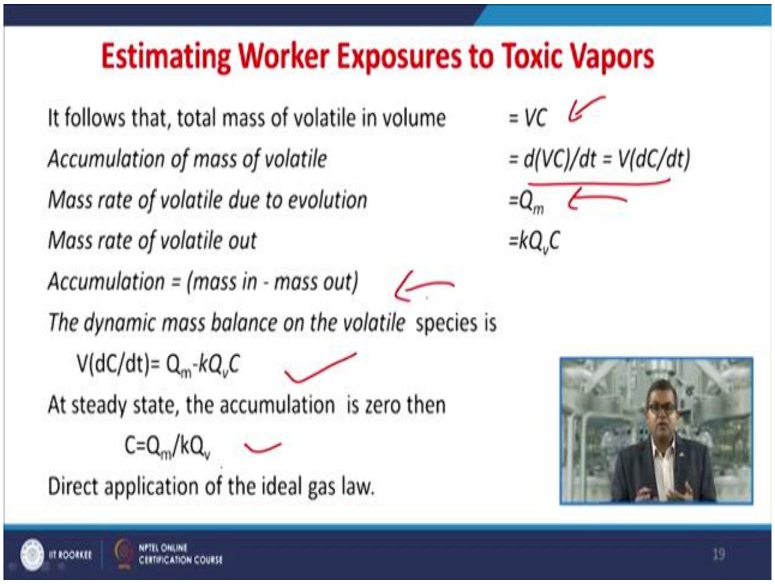

Estimating Worker Exposures to Toxic Vapors

It follows that, total mass of volatile in volume $= VC$

Accumulation of mass of volatile $= d(VC)/dt = V(dC/dt)$

Mass rate of volatile due to evolution $= Q_m$

Mass rate of volatile out $= kQ_vC$

Accumulation = (mass in - mass out)

The dynamic mass balance on the volatile species is

$$V(dC/dt) = Q_m - kQ_vC$$

At steady state, the accumulation is zero then

$$C = Q_m/kQ_v$$

Direct application of the ideal gas law.

Now, it follows that the total mass of volatile in volume is VC, because C is the concentration and V is the volume, the accumulation of mass of volatile is this one, mass weight of volatile due to evaluation is Q_m,

accumulation = (mass in - mass out)

The dynamic mass balance on the volatile species is given by this particular expression. So, at a steady state the accumulation is assumed to be 0, then,

$C = Q_m / k\, Q_v$

I mean sometimes you may take an assumption of direct, direct assumption of ideal gas law so, if you say this.

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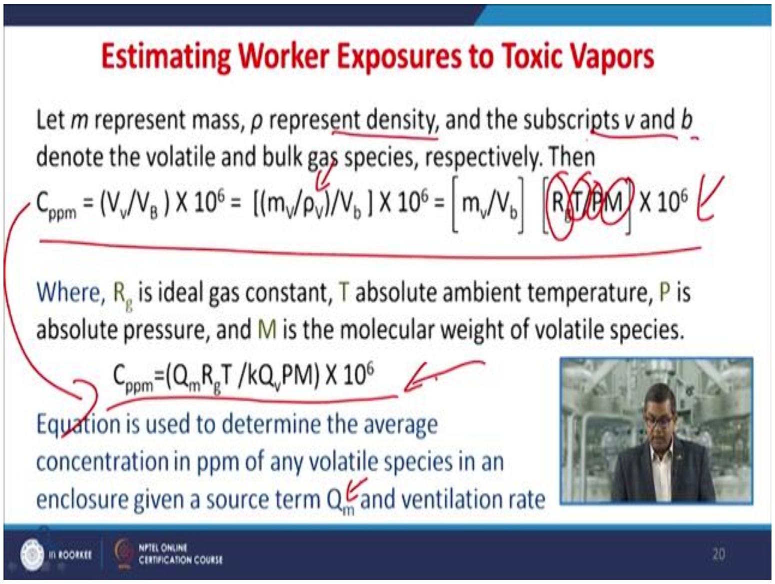

Estimating Worker Exposures to Toxic Vapors

Let *m* represent mass, ρ represent density, and the subscripts *v* and *b* denote the volatile and bulk gas species, respectively. Then

$$C_{ppm} = (V_v/V_B) \times 10^6 = [(m_V/\rho_V)/V_b] \times 10^6 = \left[m_v/V_b\right] \left[R_g T/PM\right] \times 10^6$$

Where, R_g is ideal gas constant, T absolute ambient temperature, P is absolute pressure, and M is the molecular weight of volatile species.

$$C_{ppm} = (Q_m R_g T / k Q_v PM) \times 10^6$$

Equation is used to determine the average concentration in ppm of any volatile species in an enclosure given a source term Q_m and ventilation rate

Then you can get this particular mathematical expression to estimate that what is the concentration in parts per million.

$$C_{ppm} = (V_v/V_B) \times 10^6 = [(m_v/\rho_v)/V_b] \times 10^6 = [m_v/V_b]\,[R_g T / PM] \times 10^6$$

Remember, there are so many factors like ρ, ρ represent the density and subscripts v and b they are denotes the volatile and bulk gas species and Rg is the gas constant, T is a temperature and P is the pressure, M is the molecular weight.

So, by application of your regular mass transfer theory, you can find out that what is the concentration in parts per million, so that you can analyze that based on the TLV-TWA information you can analyze that workers are exposed or over exposed or under exposed. Sometimes you may take certain assumption. So, you can reduce that to a particular formula up to

$$C_{ppm} = \left(Q_m R_g T / k\, Q_v\, P\, M \right) \times 10^6$$

This equation used to determine the average concentration in parts per million of any volatile species in an enclosure given a source term Qm, that is the rate of evaluation and ventilation rate QV.

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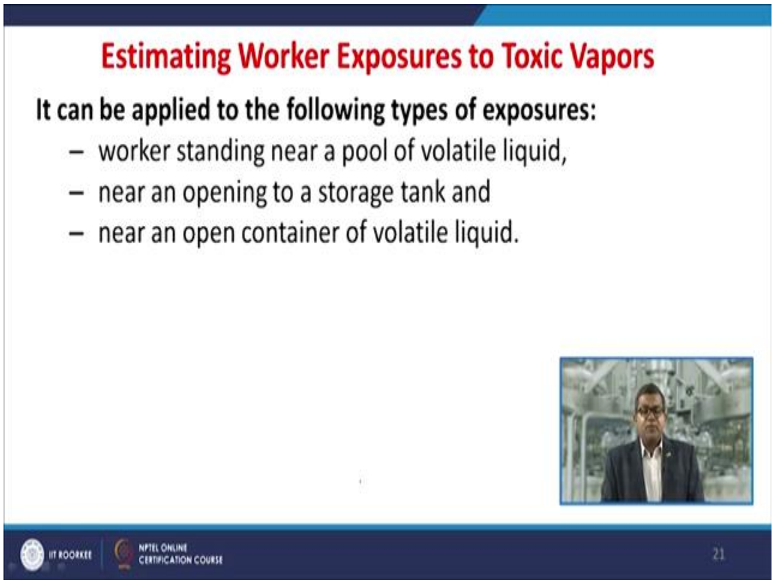

Estimating Worker Exposures to Toxic Vapors

It can be applied to the following types of exposures:

- worker standing near a pool of volatile liquid,
- near an opening to a storage tank and
- near an open container of volatile liquid.

Now, this particular thing and some now, if you find this then you can integrate the things accordingly you can get the exposure over and above that particular working pool. Now, this particular aspect can be applied to the different type of exposures like workers standing near a pool of a volatile liquid like I am standing over here, near an opening to a storage tank, near an open container of volatile liquid.

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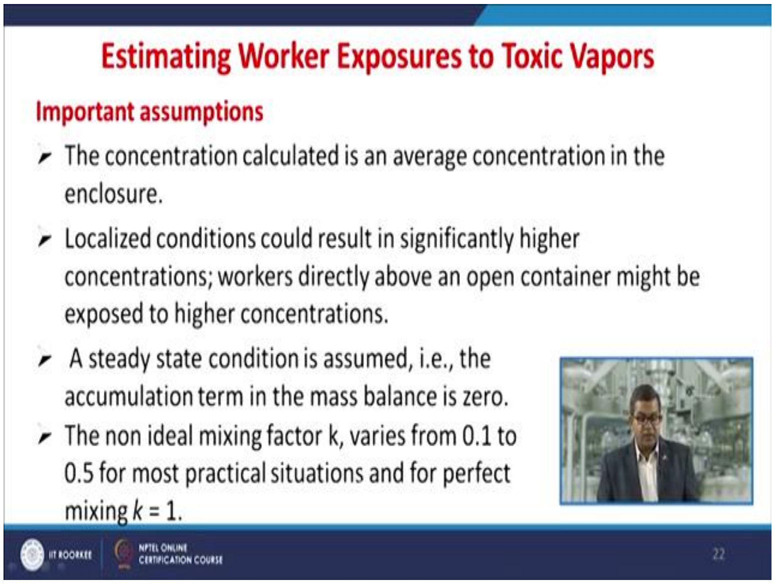

Estimating Worker Exposures to Toxic Vapors

Important assumptions

- The concentration calculated is an average concentration in the enclosure.
- Localized conditions could result in significantly higher concentrations; workers directly above an open container might be exposed to higher concentrations.
- A steady state condition is assumed, i.e., the accumulation term in the mass balance is zero.
- The non ideal mixing factor k, varies from 0.1 to 0.5 for most practical situations and for perfect mixing $k = 1$.

We have taken certain important assumptions while deriving this particular formula. The concentration calculated is an average concentration in the enclosure that means we have assumed the temperature, pressure throughout is constant and even area sometimes area is also variable, so it is constant. Localized condition could result in significant higher concentration and worker directly above an open container might be exposed to higher concentration like this, I am directly exposed to the concentration and if I am a bit away, then definitely the concentration profile would be change.

A study state condition is assumed that is the accumulation term in mass balance is 0, the non-ideal mixing factor k varies from 0.1 to 0.5 for most practical situation and perfect mixing it is k is equal to 1.

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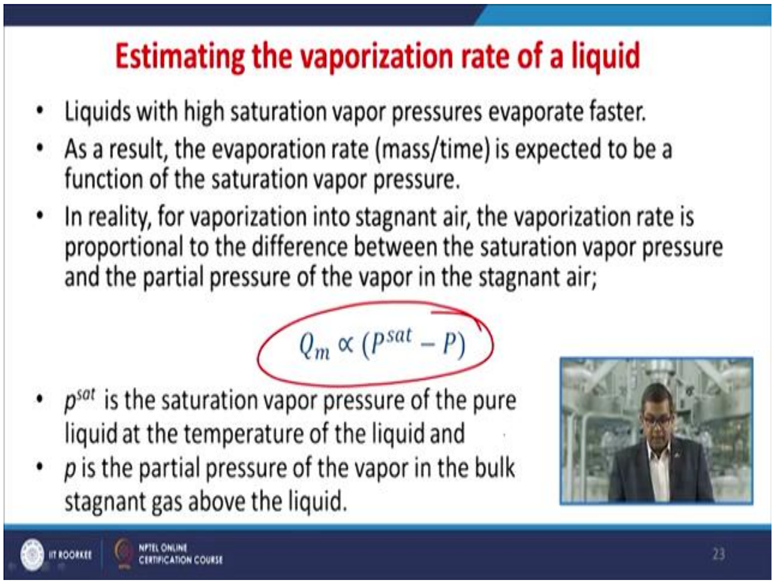

Estimating the vaporization rate of a liquid

- Liquids with high saturation vapor pressures evaporate faster.
- As a result, the evaporation rate (mass/time) is expected to be a function of the saturation vapor pressure.
- In reality, for vaporization into stagnant air, the vaporization rate is proportional to the difference between the saturation vapor pressure and the partial pressure of the vapor in the stagnant air;

$$Q_m \propto (P^{sat} - P)$$

- p^{sat} is the saturation vapor pressure of the pure liquid at the temperature of the liquid and
- p is the partial pressure of the vapor in the bulk stagnant gas above the liquid.

Now, another thing is that to how we can estimate the vaporization rate of a liquid, liquid with higher saturation vapor pressure usually evaporate fast as a result the evaporation rate mass per time it is expected to be the function of saturation vapor pressure. In reality, for vaporization into stagnant air, the vaporization rate is proportional to the difference between the saturation vapor pressure and a partial pressure of the vapor in the stagnant air and it is usually expressed by this particular formula:

$$Q_m \propto (P^{sat} - P)$$

Now, P saturation usually the saturation pressure, the saturation vapor pressure of the pure liquid at the temperature of the liquid and P is the partial pressure of the vapor in the bulk stagnant gas just above the liquid.

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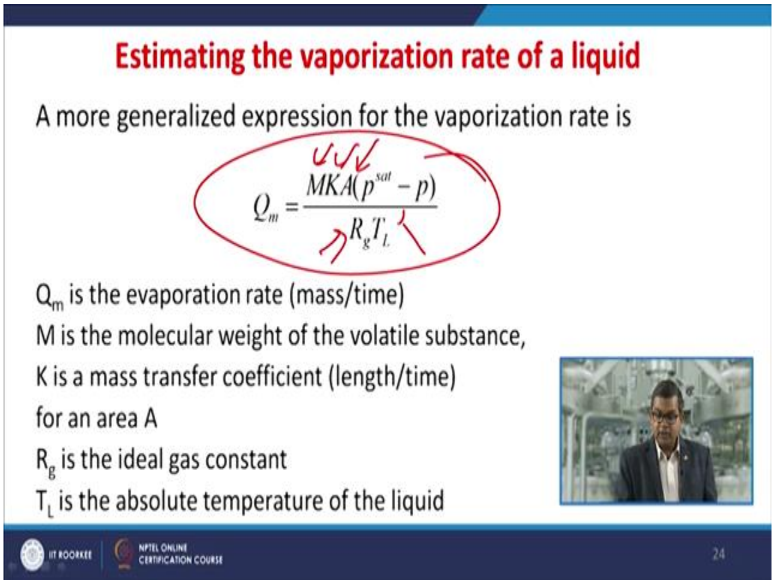

Estimating the vaporization rate of a liquid

A more generalized expression for the vaporization rate is

$$Q_m = \frac{MKA(p^{sat} - p)}{R_g T_L}$$

Q_m is the evaporation rate (mass/time)

M is the molecular weight of the volatile substance,

K is a mass transfer coefficient (length/time)

for an area A

R_g is the ideal gas constant

T_L is the absolute temperature of the liquid

Now we can have this more generalized expression and for the vaporization rate:

$$Q_m = \frac{MKA\,(p^{sat} - p)}{R_g T_L}$$

this Q_m is the obviously the evaporation rate, M is the molecular weight of the volatile substance, k is the mass transfer coefficient having the unit of length per time, A is the area in question, Rg is the gas (constant) ideal gas constant and TL is the absolute temperature of the liquid.

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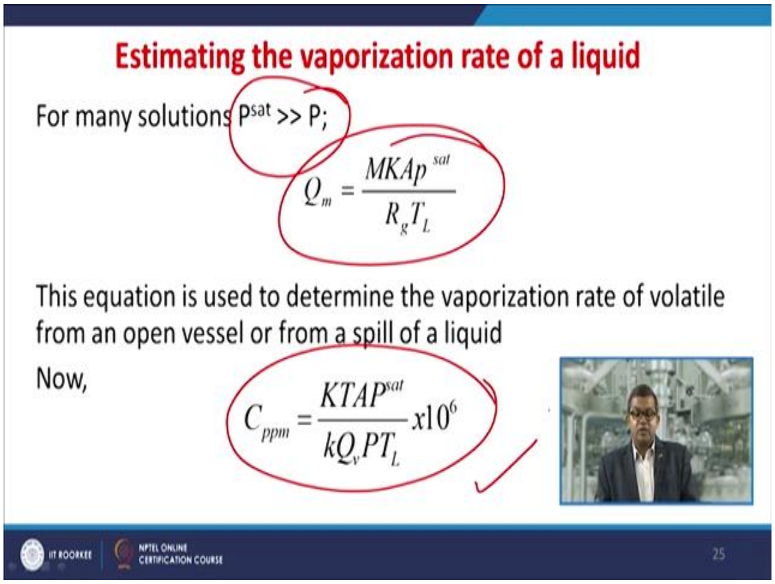

Estimating the vaporization rate of a liquid

For many solutions $P^{sat} >> P$;

$$Q_m = \frac{MKAp^{sat}}{R_g T_L}$$

This equation is used to determine the vaporization rate of volatile from an open vessel or from a spill of a liquid

Now,

$$C_{ppm} = \frac{KTAP^{sat}}{kQ_v PT_L} x10^6$$

Now, for many situations:

$$P^{sat} \gg P;$$

then this formula reduces to:

$$Q_m = \frac{MKAp^{sat}}{R_g T_L}$$

Now, this equation is used to determine the vaporization rate of volatile from an open vessel or from a spill of liquid. So, if you recall the previous formula to calculate the concentration in parts per million, if you substitute the Q_m to that particular formula, we get this expression through which we can analyze the worker exposure to the vaporization of a liquid.

$$C_{ppm} = \frac{KTAP^{sat}}{kQ_v PT_L} \times 10^6$$

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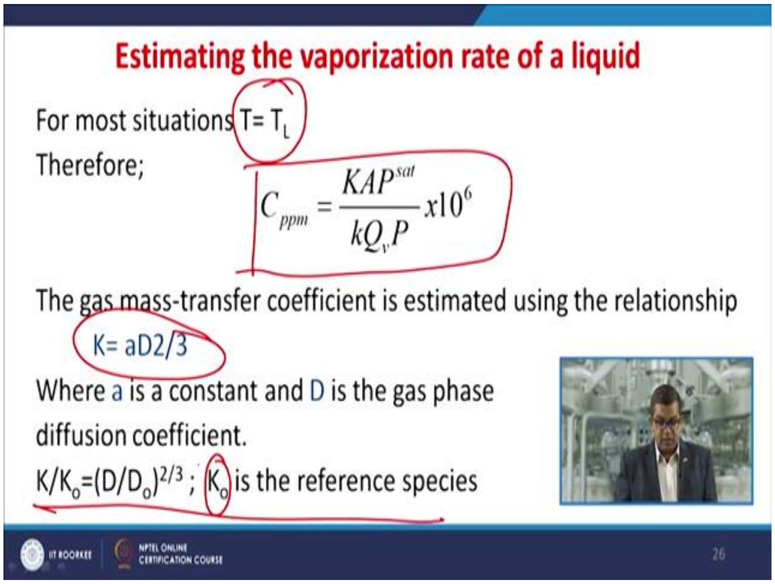

Estimating the vaporization rate of a liquid

For most situations $T= T_L$

Therefore;

$$C_{ppm} = \frac{KAP^{sat}}{kQ_v P} x 10^6$$

The gas mass-transfer coefficient is estimated using the relationship

K= aD2/3

Where a is a constant and D is the gas phase diffusion coefficient.

$K/K_o=(D/D_o)^{2/3}$; K_o is the reference species

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In most of the situation, this $T = T_L$

So, we can reduce this formula to

$$C_{ppm} = \frac{KAP^{sat}}{kQ_v P} \times 10^6$$

k is the mixing factor, Q_V is the rate of ventilation. The gas mass transfer coefficient is usually estimated by this particular formula,

$K = aD^{2/3}$

where a is a constant and D is the gas phase diffusion coefficient. So, by this way, if we have K_o as the reference species, we can have this formula:

$K/K_o = (D/D_o)^{2/3}$

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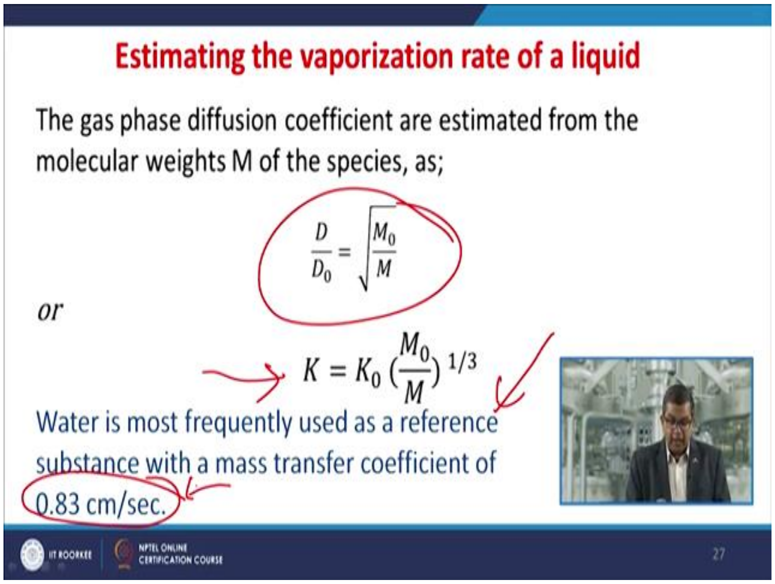

Estimating the vaporization rate of a liquid

The gas phase diffusion coefficient are estimated from the molecular weights M of the species, as;

$$\frac{D}{D_0} = \sqrt{\frac{M_0}{M}}$$

or

$$K = K_0 \left(\frac{M_0}{M}\right)^{1/3}$$

Water is most frequently used as a reference substance with a mass transfer coefficient of 0.83 cm/sec.

And if we apply this formula and reduces it become out to

$$\frac{D}{D_o} = \sqrt{\frac{M_o}{M}}$$

$$K = K_o \left(\frac{M_o}{M}\right)^{1/3}$$

Now, water is usually or sometimes or most frequently used as a reference substance with the mass transfer coefficient of 0.83 centimeters per second, be particular about the unit and be particular about the value.

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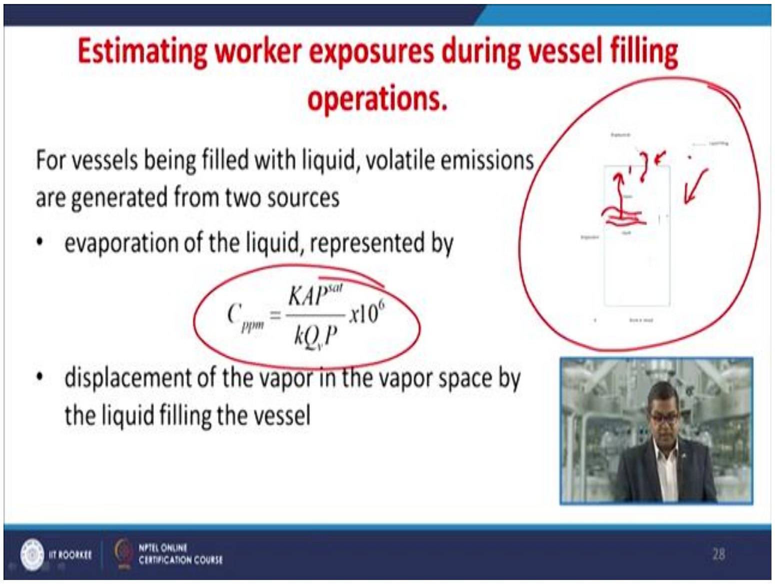

Estimating worker exposures during vessel filling operations.

For vessels being filled with liquid, volatile emissions are generated from two sources

- evaporation of the liquid, represented by

$$C_{ppm} = \frac{KAP^{sat}}{kQ_v P} x10^6$$

- displacement of the vapor in the vapor space by the liquid filling the vessel

Sometimes another, in another scenario where any worker is filling a vessel with a toxic liquid or a flammable liquid. Now, there are two type of scenario based on the area available for evaluation of toxic or flammable vapor. Now in this figure, you can see, this is the area which is available for escaping the vapors. Second thing is that based on that molecular weight, based on the temperature, (the work) the vapor which is being generated throughout is displaced throughout.

So, based on the vessel filling rate, that at what is the filling rate or what is at what rate the liquid is pumping inside the vessel? Based on this particular aspect, the concentration of the vapor may vary from this level to this level, here you will find more enriched vapor and as long as it goes up the concentration may change. So, based on this particular aspect, because initially you just assume a scenario when this vessel is empty and just a worker started the vessel filling operation at start up there is low bulk volume and it is this chamber is, this vessel is filled with air. So, the concentration of the toxic substance may be on the lower side.

But as long as the, the vessel is continuously being filled, then there is a continuous displacement of vapor and all these vapors or toxic vapors, they are coming out from this opening. So, there may be a chance that concentration may vary accordingly, there may be chance that how the worker is being exposed, what is the, it is just like that you are filling your petrol tank in a petrol station or a petrol pump, where when the nozzle is being inserted a small opening is there and you may experience that there is a smell of petrol and continuously it is being changing, this is the same phenomena.

Now, this is a very important phenomena and you cannot apply our previous steps to calculate the concentration in parts per million, because here the rate of vessel filling is also playing a vital role. So, the vessel if being filled with the liquid the volatile emissions, they are generated from two sources, evaporation of the liquid usually represented by this formula earlier we have discussed this formula and the displacement of a vapor in the vapor space by the liquid filling the vessel.

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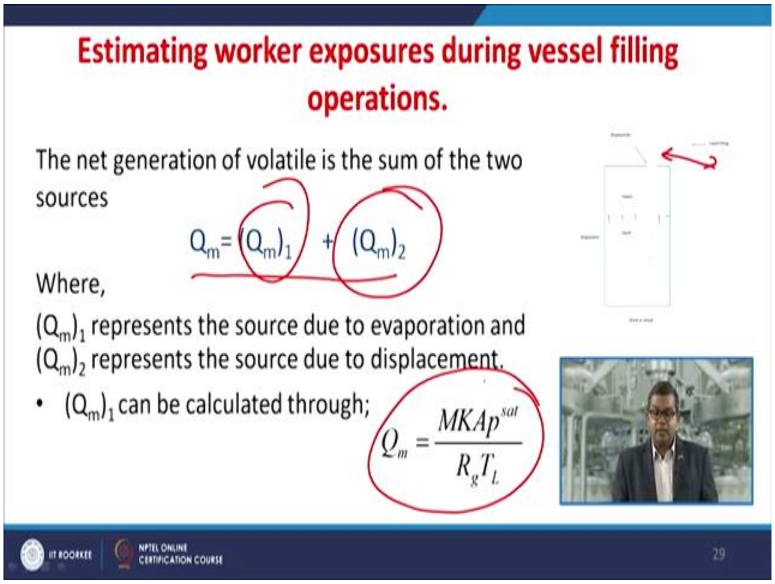

Estimating worker exposures during vessel filling operations.

The net generation of volatile is the sum of the two sources

$$Q_m = (Q_m)_1 + (Q_m)_2$$

Where,

$(Q_m)_1$ represents the source due to evaporation and $(Q_m)_2$ represents the source due to displacement.

- $(Q_m)_1$ can be calculated through; $Q_m = \frac{MKAp^{sat}}{R_g T_L}$

So, the net generation at this point, the net generation of the volatile is the sum of two sources. One is the source due to evaporation and second one is the source due to the displacement. So, Qm you can calculate easily through this formula:

$Q_m = (Q_m)_1 + (Q_m)_2$

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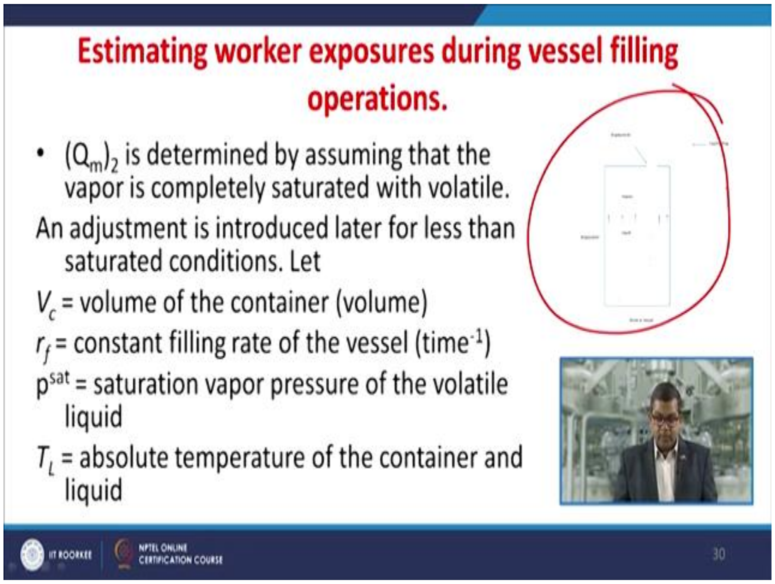

Estimating worker exposures during vessel filling operations.

- $(Q_m)_2$ is determined by assuming that the vapor is completely saturated with volatile.

An adjustment is introduced later for less than saturated conditions. Let

V_c = volume of the container (volume)

r_f = constant filling rate of the vessel (time^{-1})

p^{sat} = saturation vapor pressure of the volatile liquid

T_L = absolute temperature of the container and liquid

For $(Q_m)_2$ is determined by assuming that the vapor is completely saturated with volatile. So, you can introduce an adjustment which we will discuss that whether it is a splash filling or whether it is a continuous filling. Now, let us say that VC is the volume of the container, this container is having the volume VC, rf is the constant filling rate of the vessel because we have assumed, but sometimes it is not being followed, then rf we see that it is the constant filling rate of the vessel and p saturation is the saturation vapor pressure of the volatile liquid and TL is the absolute temperature of the container and liquid.

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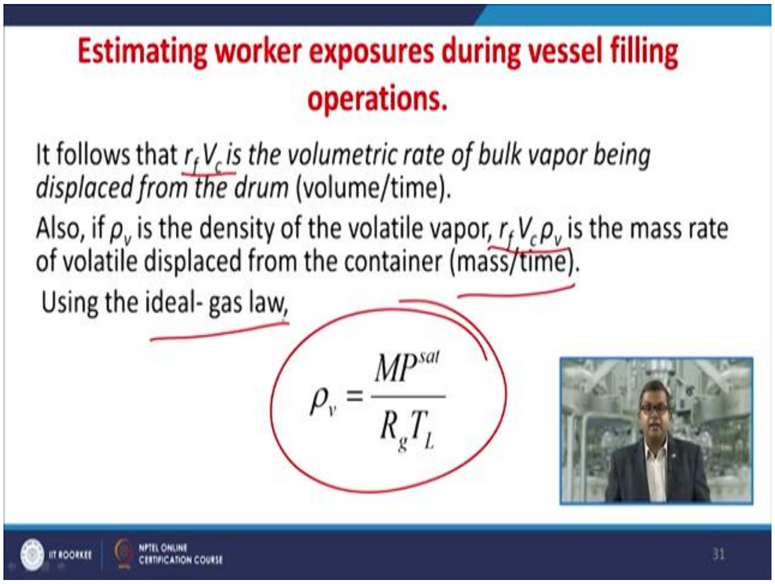

Estimating worker exposures during vessel filling operations.

It follows that $r_f V_c$ *is the volumetric rate of bulk vapor being displaced from the drum* (volume/time).

Also, if ρ_v is the density of the volatile vapor, $r_f V_c \rho_v$ is the mass rate of volatile displaced from the container (mass/time).

Using the ideal- gas law,

$$\rho_v = \frac{MP^{sat}}{R_g T_L}$$

So, it follows that rf VC is the volumetric rate of bulk vapor being displaced from the drum in terms of volume per time, volume unit time. Now, if ρ_v is the density of the volatile vapor, so r_f VC and ρ_v is the mass rate of volatile displaced from the container that is mass per time. So, if you assume the ideal gas law, then

$$\rho_v = \frac{MP^{sat}}{R_g T_L}$$

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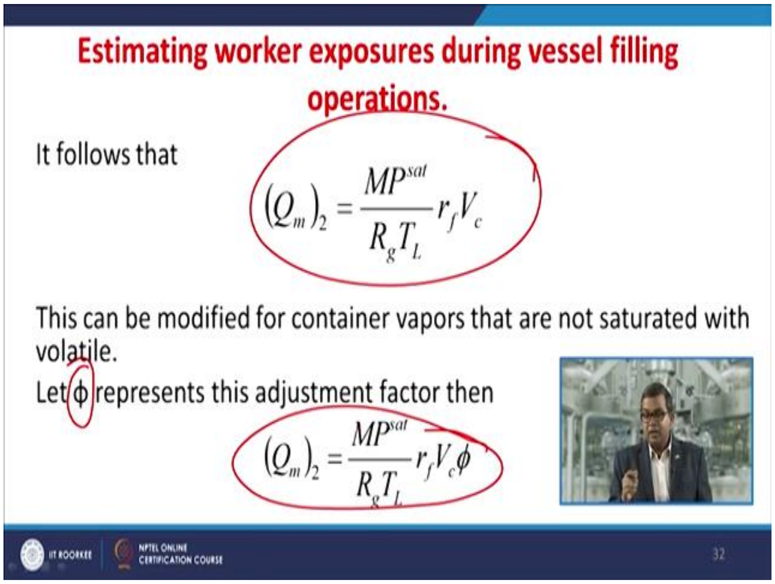

Estimating worker exposures during vessel filling operations.

It follows that

$$(Q_m)_2 = \frac{MP^{sat}}{R_g T_L} r_f V_c$$

This can be modified for container vapors that are not saturated with volatile.

Let ϕ represents this adjustment factor then

$$(Q_m)_2 = \frac{MP^{sat}}{R_g T_L} r_f V_c \phi$$

So, it follows that:

$$(Q_m)_2 = \frac{MP^{sat}}{R_g T_L} r_f V_c$$

Now, this can be modified for the container vapors that are not saturated with the volatile. Now, this ϕ is the adjustment factor.

So if you introduce this ϕ, because we have previously discussed that why we are introducing this adjustment factor,

So,

$$(Q_m)_2 = \frac{MP^{sat}}{R_g T_L} r_f V_c \varphi$$

because the filling operation carries a different type of domain. So that is why we have introduced this adjustment factor.

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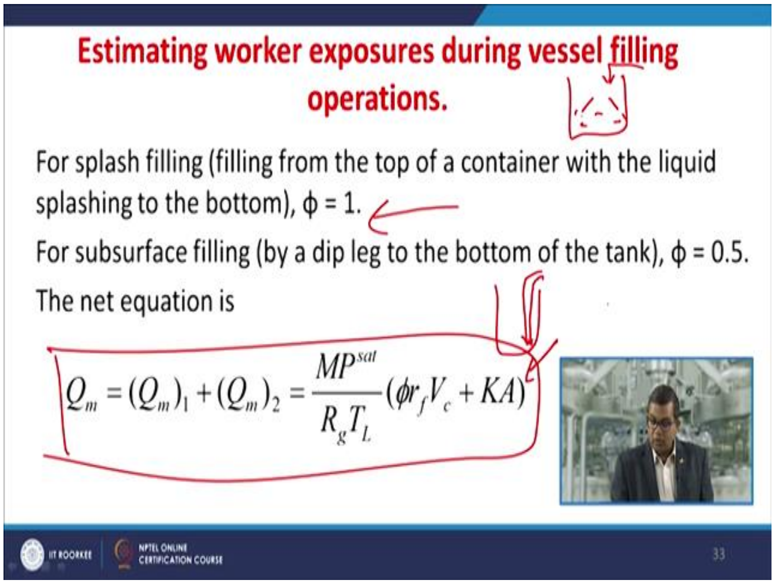

Estimating worker exposures during vessel filling operations.

For splash filling (filling from the top of a container with the liquid splashing to the bottom), ϕ = 1.

For subsurface filling (by a dip leg to the bottom of the tank), ϕ = 0.5.

The net equation is

$$\boxed{Q_m = (Q_m)_1 + (Q_m)_2 = \frac{MP^{sat}}{R_g T_L}(\phi r_f V_c + KA)}$$

So far splash filling, filling from the top of the container like this, you are filling it from the top of the container, so this may, this may create a problem formation of small droplets, so area may increase so that is why this adjustment factors being introduced. So for splash filling, filling from the top of the container with the liquid splashing to the bottom ϕ is equal to 1.

For subsurface filling, that is the dip leg to the bottom, the dip leg is like this, you are filling like this. So for subsurface filling, a dip leg of the bottom, usually ϕ is equal 0.05.

So the net equation becomes this one:

$$Q_m = (Q_m)_1 + (Q_m)_2 = \frac{MP^{sat}}{R_g T_L} \left(r_f V_c \varphi + KA \right)$$

A is the area of exposure through which the vapors are escaping.

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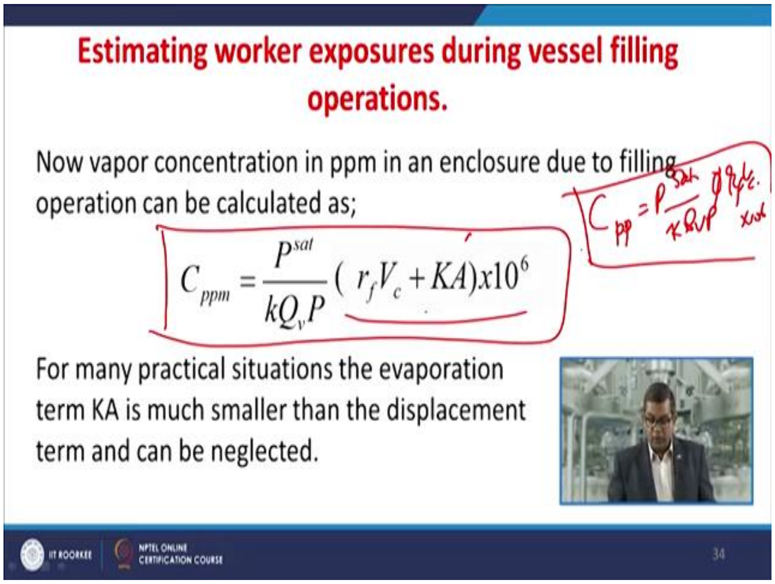

Estimating worker exposures during vessel filling operations.

Now vapor concentration in ppm in an enclosure due to filling operation can be calculated as;

$$\boxed{C_{ppm} = \frac{P^{sat}}{kQ_v P}\underline{(\ r_f V_c + KA)}x10^6}$$

$$\boxed{C_{pp} = \frac{P^{sat}}{kQ_v P} \emptyset r_f V_c \times 10^6}$$

For many practical situations the evaporation term KA is much smaller than the displacement term and can be neglected.

Now, if we wish to calculate the vapor concentration in parts per million, (during) due to this filling operation, we can put in the entire value of Q_m to the original equation and we found out that:

$$C_{ppm} = \frac{P^{sat}}{kQ_v P}\ (\ r_f V_c + KA) \times\ 10^6$$

For many practical situations the evaporation term this KA is much smaller than the displacement term and it can be neglected. So, we can eliminate this, this one and we can get:

$$C_{ppm} = \frac{P^{sat}}{kQ_v P}\ (\ r_f V_c \emptyset) \times\ 10^6$$

So, this is the original formula.

So, this in this particular aspect, we have discussed majority of aspect of vessel filling, workers exposure, continuous rate of exposure, so that we can analyze that how much my worker is being exposed to the toxic vapor and at what rate because this quantification is extremely essential. So, we have calculated this concentration and based on this concentration, we can analyze with the theoretical value, with the help of theoretical value that my workers are exposed or they are working in a safer zone.

In this module, we have discussed the various aspect of toxic vapor release, how it can be, how your worker can be exposed to the those toxic vapors. What are the different modules through which we can analyze? I am working in open pan or sometimes the area in question. Sometimes there is a continuous rate of evolution, sometimes the concentration may vary like this. In the next module, we will discuss some other aspect of like noise, radiation, some other aspect of the toxicity in the work place exposure, Thank you.