Chemical Process Safety
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Lecture 17
Introduction to Source Models

Welcome to the next lecture and chapter and that is attributed to the introduction to source models. So, in this particular chapter we will discuss different source models, they are applicable for the process safety and how we can derive the various equations applicable to these source models, we can perform the modelling.

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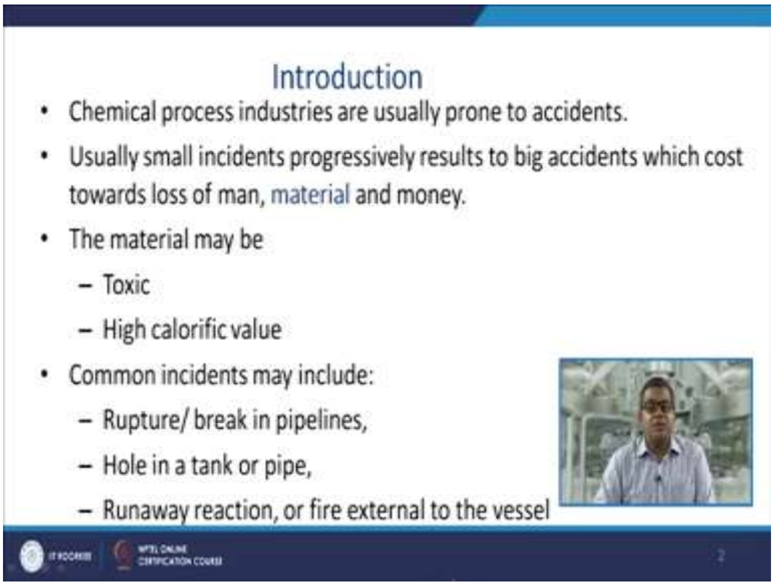

Let us have an introduction of these source models, we all agree that the chemical process industries are usually prone to accidents especially fire explosion, different type of toxic release etcetera and these incidents or these accidents they are attributed to the variety of reasons may be human, may be equipment failure may be some other things. So, usually a small incidence progressively results to a big accident which cause towards the loss of man, material and money.

And everywhere when we talk about in terms of economics everywhere there is a loss of money or economics because if any incident takes place towards the man may be fatality or may be injury or may be illness you need to pay the compensation, you have to take care of that particular human being. If there is a loss of a material then again there is an economic loss.

So, sometimes we need to take care of those small incidents which may cause a severe problem. Now, especially when we are considering the material because all these source models are attributed to the material and a process, so these materials which may be released or which may cause a severe problem they may be highly toxic they must have they may have a high calorific value, these two things, these two possibilities are there.

There may be some common incidents that may include maybe sometimes a rupture or break in pipeline, this may cause the exposure or evolution of any kind of toxic material to the atmosphere or any kind of a flammable material may get discharge into that atmosphere from the flammable vapour cloud etcetera. Sometimes, hole in a tank or a pipe may create a problem, it is not only attributed to the flammability aspect or a fire and explosion aspect or a toxic release sometimes as this leakage may create the economic losses because the material will get destroy.

There may be a chances of runaway reaction or a fire external to the extended to the vessel and these runaway reactions sometimes because of the failure of any kind of sensor because maybe sometimes of a human involvement, there is some these thermal runaway reaction or chemical runaway reaction may take place and it may create a problem to the plant. So, source models they are used to describe the discharge of the material due to the incident from the process, this is the basic methodology of all these source models.

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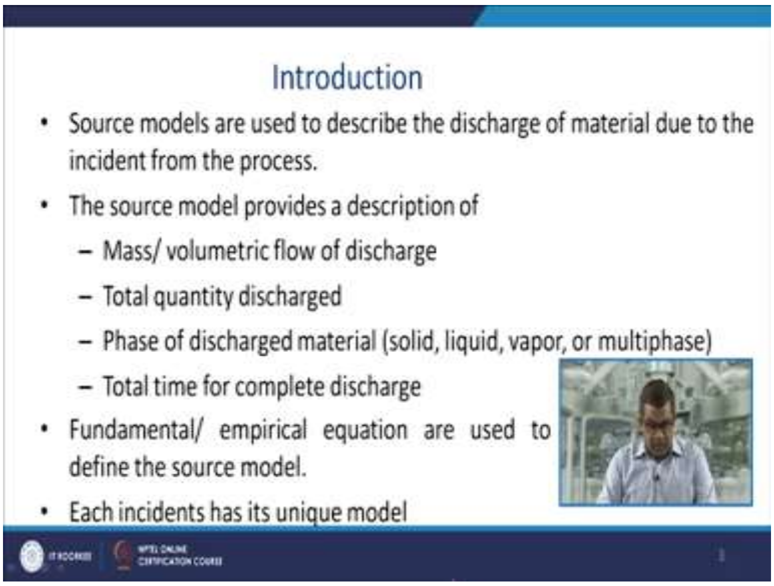

The source model provides a description of mass or a volumetric flow of discharge. The total quantity of discharge, because sometimes you need this information to assess the safety aspect of your process or your equipment. Phases of discharge material may be solid, liquid vapour or sometimes multi-phase, so this is again a very crucial issue. So, these type of description is necessary for source model, the source model description.

The total time for the complete discharge, this is again a very crucial aspect how much time is required to empty the vessel, or empty the pipeline etcetera. The fundamental or empirical equations are used to define the source model and each incident is, has it is own or unique model.

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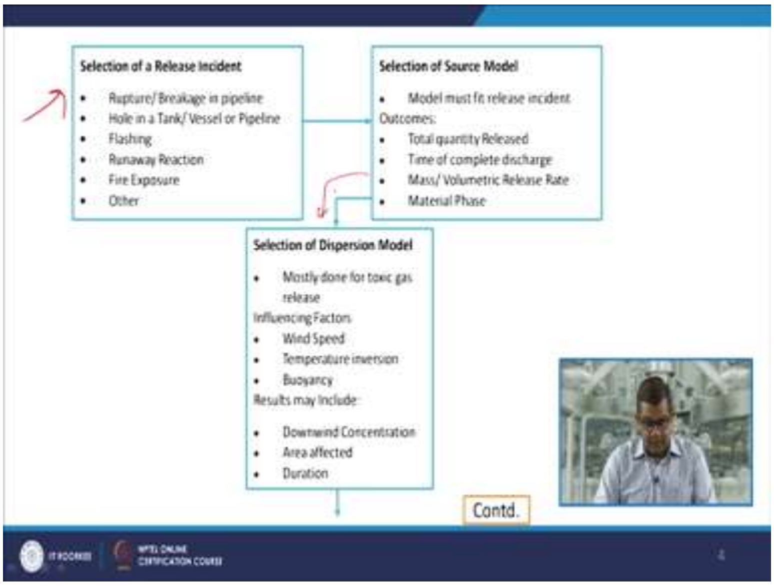

Now, let us have a look of these incidents, there are variety of incidents listed in this block that is a selection of release incident. Sometimes rupture or breakage in pipeline, sometimes a hole in a tank or a vessel or a pipeline, flashing may create a problem means from high pressure zone to the low pressure zone it may create a problem, sometimes runaway reaction may cause a problem, sometimes maybe the fire exposure creates a problem and others which may be enlisted in several aspects.

So, while you have selection of a release incident then you select and the source model thes,e the prima phase, the requirement is the model must fit the release incident. So, by this particular aspect there are certain outcome, that total quantity released you can easily find out, the time of complete discharge, the mass or volumetric release rate and the material phase. So, whenever you have carried out this one then go for the selection of dispersion model.

Mostly you, this the selection of dispersion model is done for the toxic release and sometimes influencing factors are what are the wind speed? So, while, if you go to the Bhopal gas tragedy, the wind speed was a crucial aspect for all those infertility. What is a temperature inversion? That has to be looked into by ANSI effect because sometimes the density difference may create problems.

Now, the results may include the downwind concentration, you may have about you may have a clue about the area affected and the duration.

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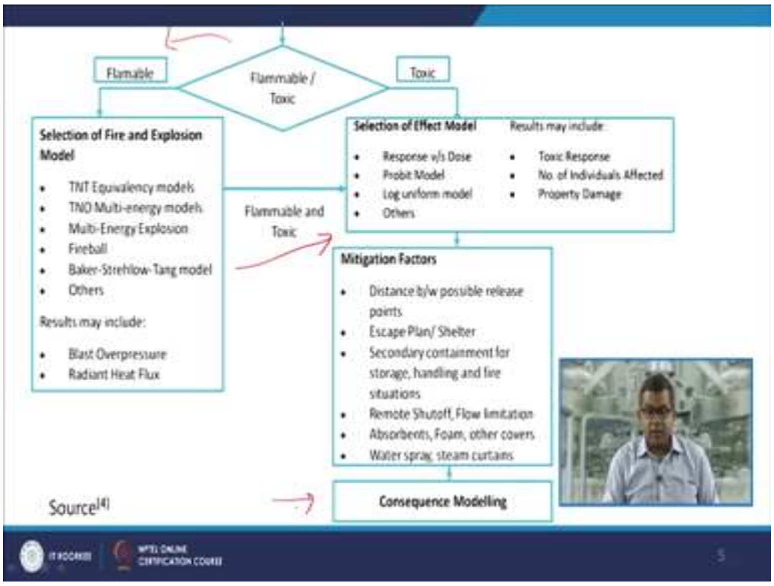

Then while, we considering the flammable or a toxic substances we can enlist two different type of scenario. So, let us have a look of the flammable aspect then the selection for the fire and explosion model you may have a look of the TNT equivalency, Trinitrotoluene equivalency model, TNO multi energy models, multi energy explosion there may be a chances of fireball then Baker-Strehlow the tang model, then different other models.

Now, result may include the blast overpressure and the radiant heat flux. So, if we consider there are flammable and a toxic both are toxic then effective model response versus dose, we have already discussed this in the toxicological studies, the profit model, the log uniform model and others. The result may include the toxic responses and number of individual what are the (individ) the quantity of individual affected and the property damage usually the property damage in case of toxic studies are bit minimum compared to the flammability aspect.

Now, there are certain mitigation factors like distance between the possible release points, escape plan or shelter aspect, secondary containment for storage handling in a fire situation. The remote shutoff, flow limitations, absorbent, foam, other covers, water spray or stream curtains etcetera. So, these are the certain scenarios then we go for the consequence modelling.

The after when we carry out this thing then we can go at further consequence modelling.

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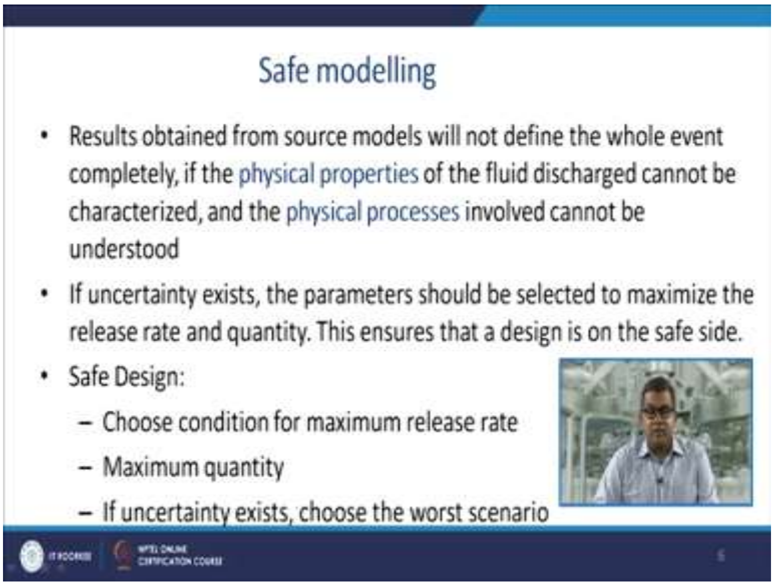

So, while we consider the safe modelling, the result obtained from source model will not define the whole event completely. Now, if the physical properties of the fluid discharge cannot be characterized and the physical process involved cannot be understood. So, if any kind of uncertainty exists, the parameter should be selected to maximize the release rate and quantity.

Now, this ensure the design is on the safe side. Now, safe design requires further certain things like choose conditions for maximum release rate, the maximum quantity and if uncertainty exists, choose the worst scenario it is just like that if you wish to design the things you may take the LPG cylinder domestic LPG cylinder and you take the maximum quality that says cylinder is completely filled 14.2 or 14.5 kilogram as applicable to the cylinder.

Now, worst scenario is that the cylinder will burst and all the entire LPG will escape from the cylinder and it will catch the fire, so this is the worst scenario.

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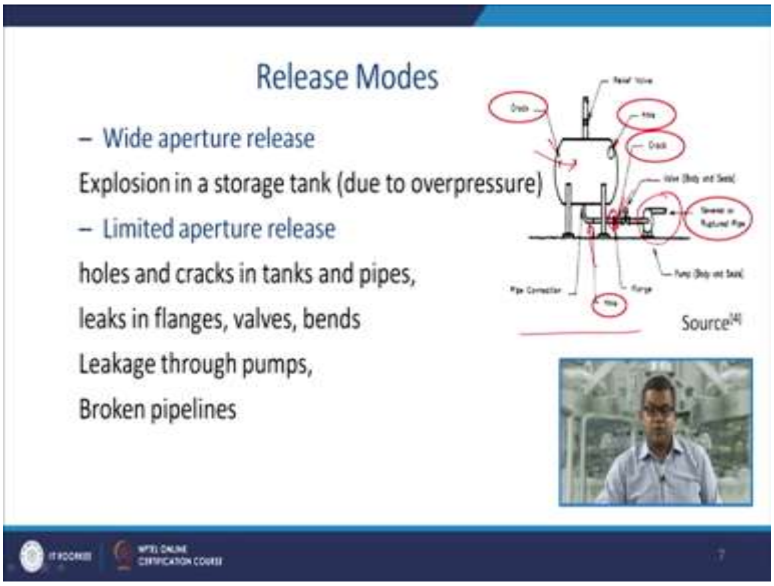

So, while you consider the release modes, so there are wide aperture release and you can have a look of this particular figure explosion in a storage tank, this is your storage tank and this explosion is mainly attributed to the overpressure. Now, there are certain limited aperture release in a hole and that there may be a hole in the tank or there may be chance of a crack in the tank or sometimes the crack may be in the pipeline, pipes sometimes leakage in the flanges, there is a the hole and there may be a leak in the flanges, sometimes leak may be through the pumps, sometimes there is a scenario of a broken pipeline.

So, there are different release modes in this particular pressure vessel or a storage tank.

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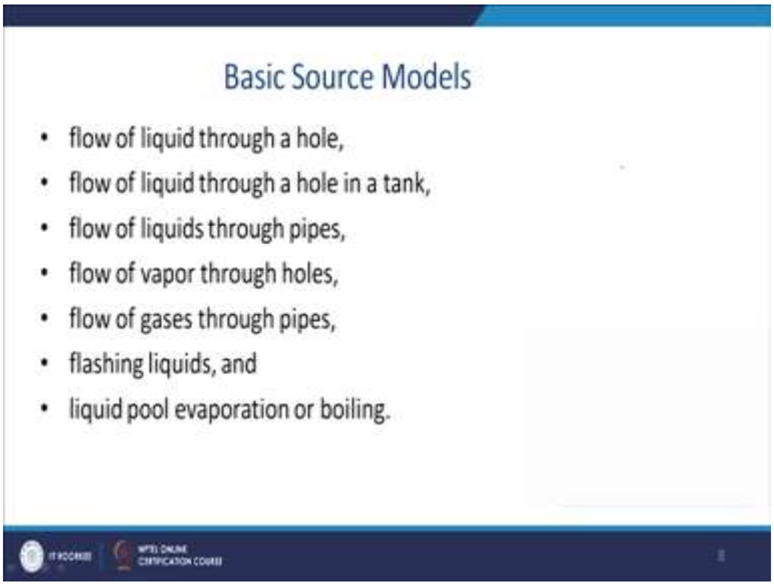

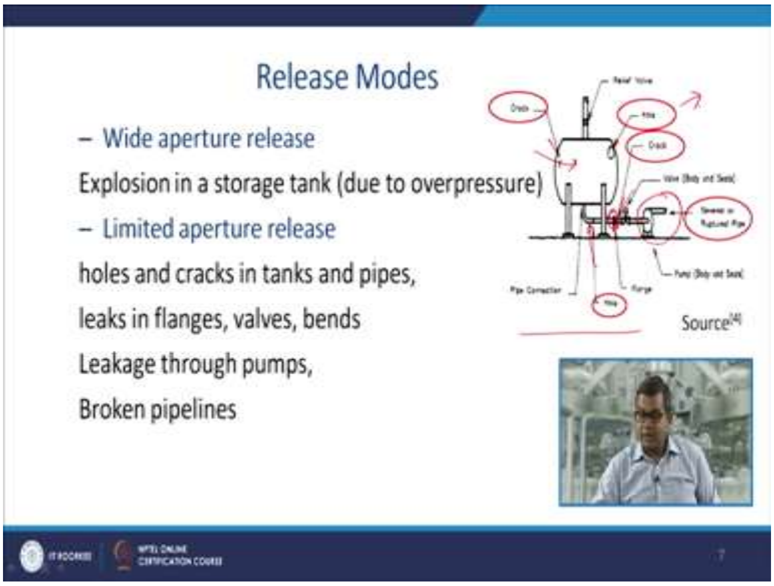

Now, while considering the basic source model, there are seven things which we need to know that is the flow of liquid through a hole because if you consider the previous one, what is the flow of a liquid through hole? And consider this scenario is bit different from the scenario at this point. Then flow of liquid through a hole in tank, flow of liquid through pipes, flow of vapour through holes, flow of gases through pipes, flashing liquid and a liquid pool evaporation or boiling.

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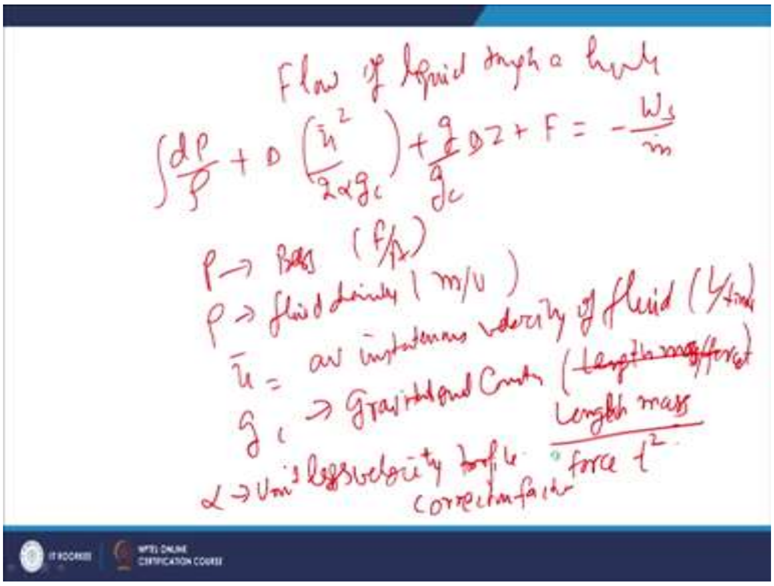

Now, let us consider first thing that is the flow of liquid through a hole. So, basically this particular thing is attributed to the mechanical energy balance equation which describes the various energy forms associated with the flowing fluids. So, this is the basic mechanical engineering equation, mechanical energy balance equation

$$\int \frac{dP}{\rho} + \Delta\left(\frac{\overline{u}^2}{2\alpha g_c}\right) + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}$$

Where P is pressure in the force/ area unit, rho is the fluid density, mass/ unit volume.

(So), and u bar is the average instantaneous velocity of the fluid, instantaneous velocity of the fluid length per time, g_c is the gravitational constant that is length mass per force times square, alpha is the unitless velocity profile correction factor (unitless) velocity profile correction factor .

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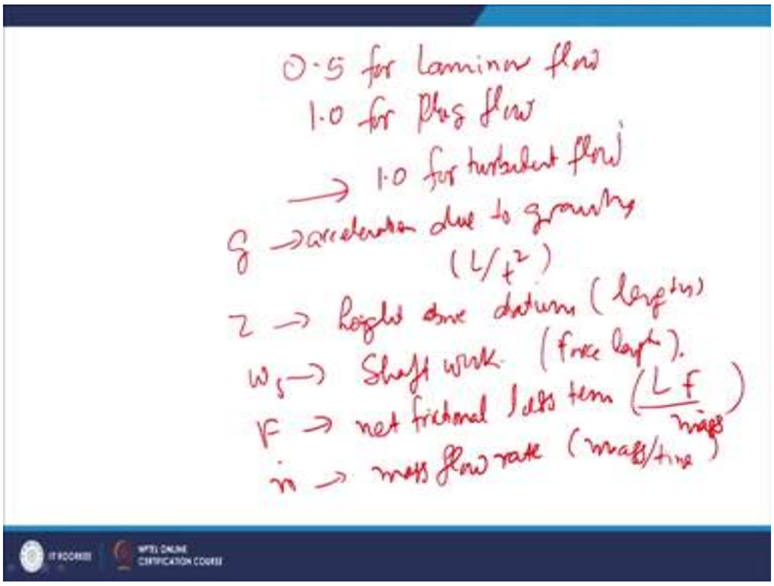

Usually alpha is having the value of 0.5 for a laminar flow 0.5 for laminar flow and 1.0 for plug flow it tends for to 1.0 for turbulent flow. Now, g is the acceleration due to gravity having the units in terms of length times square, z is the height above datum and length unit, Ws is the shaft work that is the force length, F is the net frictional loss term that is length force upon the mass and m is the mass flow rate that is mass per unit time.

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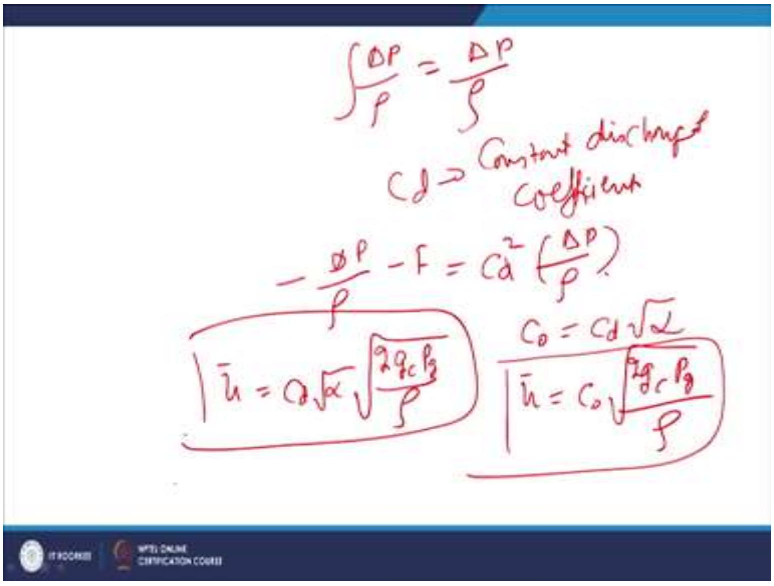

For incompressible liquid, the density is constant, so we may keep this formula like this

$$\int \frac{\Delta P}{\rho} = \frac{\Delta P}{\rho}$$

and the frictional losses in the leak are approximated by a constant discharge coefficient Cd, Cd is the constant discharge coefficient. So, the equation is coming out to be

$$-\frac{\Delta P}{\rho} - F = {C_d}^2 (\frac{\Delta P}{\rho})$$

It is just like this after applying all these assumptions.

So, (the average leak), average discharge velocity from leak can be determined as

$$\bar{u} = C_d \sqrt{\alpha} \sqrt{\frac{2 g_c P_g}{\rho}}$$

Now, if we take

$$C_0 = C_d \sqrt{\alpha}$$

then

$$\bar{u} = C_0 \sqrt{\frac{2 g_c P_g}{\rho}}$$

So this is after certain derivation after then the mass flow rate Qm will be.

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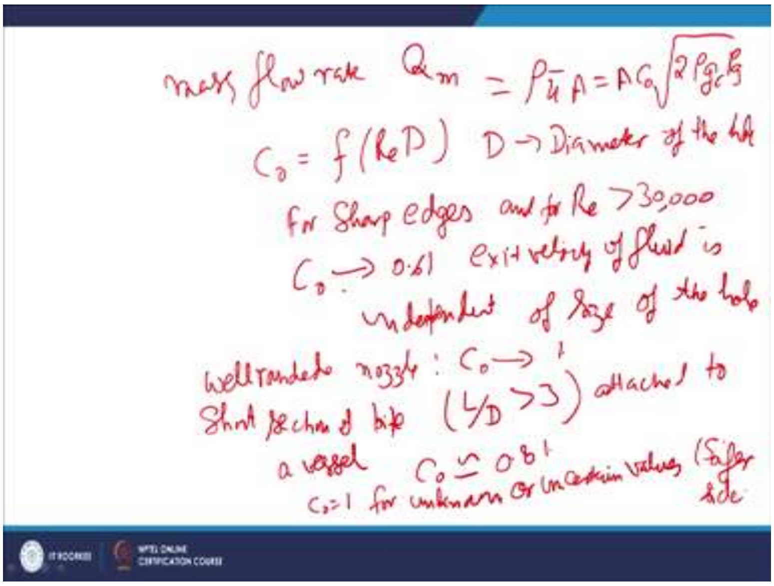

The mass flow rate Q_m is equal to

$$Q_m = \rho\overline{u}A = AC_0\sqrt{2\rho g_c P_g}.$$

So, the total mass of liquid is spilt depend on the total time that leaks is active,

So, $C_0 = f\,(Re, D)$;

Re stands for Reynolds number, D, now D is the diameter of the hole. Now, for sharp edges and usually this happens for sharp edges and Reynolds number is greater than 30,000, so C naught tends to 0.61 the exit velocity of fluid is independent of size of the hole.

So, now various values of discharge coefficient we may enlist these various different values of discharge coefficient, so for well-rounded nozzle C naught tends to 1, for short sections of pipe L by D is greater than 3, length upon diameter, attached to the vessel which is which we have previously discussed and shown in the slide, to a vessel Cnaught is almost 0.81. So, you may use C naught is equal to 1 for unknown or uncertain values, for a safer side.

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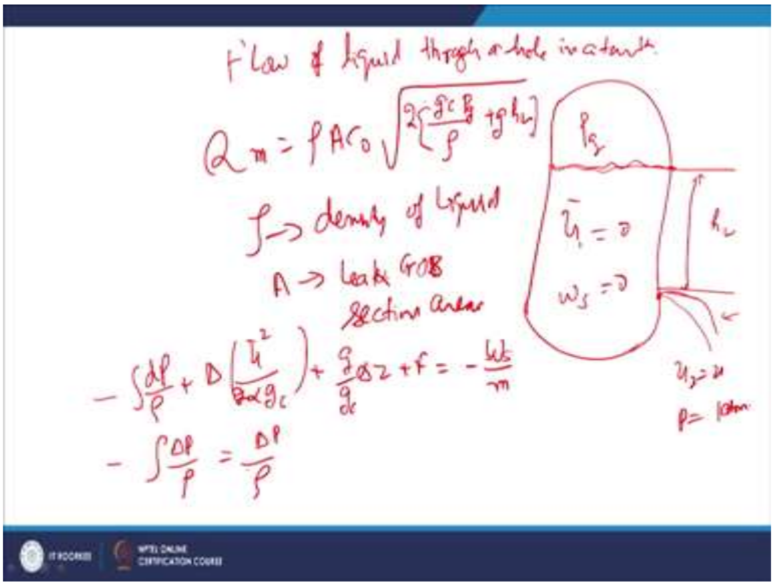

Now, let us take another aspect that is a flow of liquid through a hole in a tank, flow of liquid through a hole in a tank. Now, this is the tank, like this, we are having certain liquid is filled over here and you are having a hole at this juncture, so you may have a different profiles like this and this is the height of liquid "h_L", the pressure exerted "P_g", initial velocity is 0, "W_s" is 0 and "u_2" at this juncture is let us say "u," and "P" is equal to 1 atmosphere because it is exposed to atmosphere.

So, $Q_m = \rho A C_0 \sqrt{2\,[\frac{g_c P_g}{\rho} + g h_L]}$,

like this, "ρ" is the density of the liquid and "A" is the leak cross section area, so and usually your usual physics phenomena applies over here. So, usually so whenever I mean if you have a hole develop because it is a very common practice, so hole develop in a tank at a height h_L below the fluid level, this is your fluid initial fluid level because when this hole is developed this fluid level will deplete.

So, a flow of liquid through this hole represented by a mechanical energy equation or a mechanical energy balance equation and you may take one assumption that liquid is incompressible in all aspect. So, the (mech) mechanical energy balance equation is

$$\int \frac{dP}{\rho} + \Delta\left(\frac{\bar{u}^2}{2\alpha g_c}\right) + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}$$

$$\int \frac{\Delta P}{\rho} = \frac{\Delta P}{\rho},$$

we have taken this assumptions previously.

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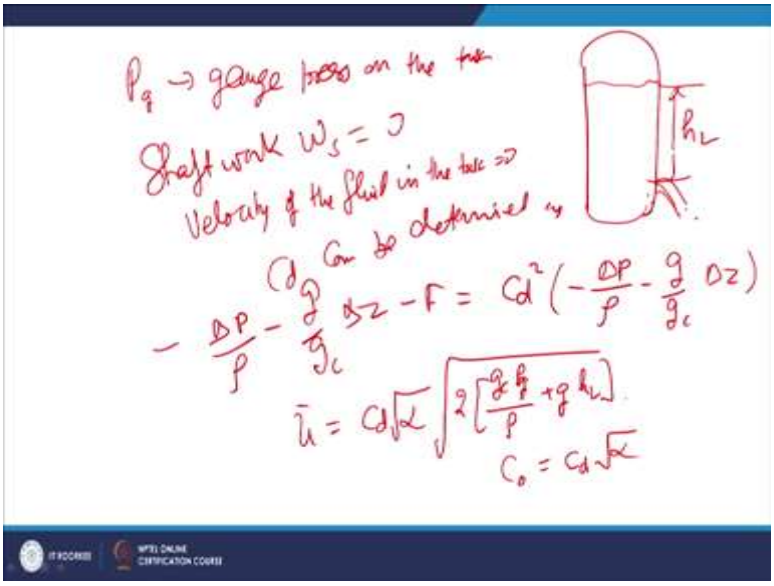

So, the assumptions we what we have taken, that is Pg is the gauge pressure on the tank. I am again redrawing the tank figure over here, here is the hole, hole, this is the liquid level this is hL. Now, external gauge pressure is equal to atmospheric pressure, the shaft work W_s is equal to 0 and the velocity of the fluid in the tank, of the fluid in the tank is equal to 0, so discharge coefficient C_d can be determined as

$$-\frac{\Delta P}{\rho}-\frac{g}{g_c}\Delta z-F=C_d{}^2\left(-\frac{\Delta P}{\rho}-\frac{g}{g_c}\Delta z\right)$$

Now, if we solve this equation for getting the average instantaneous distance velocity from the leak, that is

$$\overline{u}=C_d\sqrt{\alpha}\sqrt{2[\frac{g_cP_g}{\rho}+gh_L]}$$

Now, if we say that

if $C_0 = C_d\sqrt{\alpha}$

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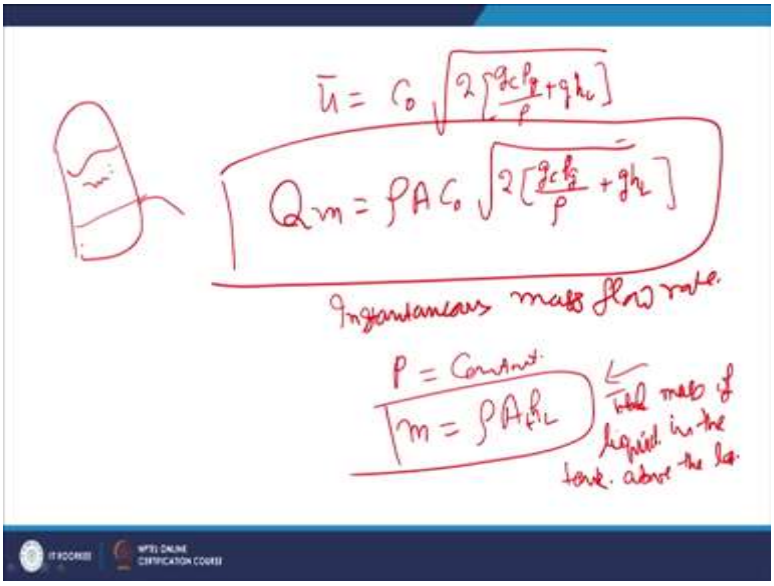

Then,

$\overline{u} = C_0\sqrt{2[\frac{g_c P_g}{\rho} + gh_L]}$.

So, therefore the instantaneous mass flow rate will be given as

$Q_m = \rho A C_0\sqrt{2[\frac{g_c P_g}{\rho} + gh_L]}$

through which you can assess the instantaneous mass flow rate, this is instantaneous mass flow rate. Now, as the tank empties, the liquid height decreases and the velocity and mass flow rate decreases.

Now, if the vessel was fill out with an inert gas to prevent the explosion or was vented to the atmosphere then the gauge pressure “P”, “P” on the surface of the liquid is constant. So, for a tank constant cross sectional areas having the At, the total mass of liquid in the tank above leak is

$m = \rho A_t h_L$

So this is the total mass of liquid, mass of liquid in the tank above the leak, that is like this, you are having this, you are having the leak over here, so this is the total mass.

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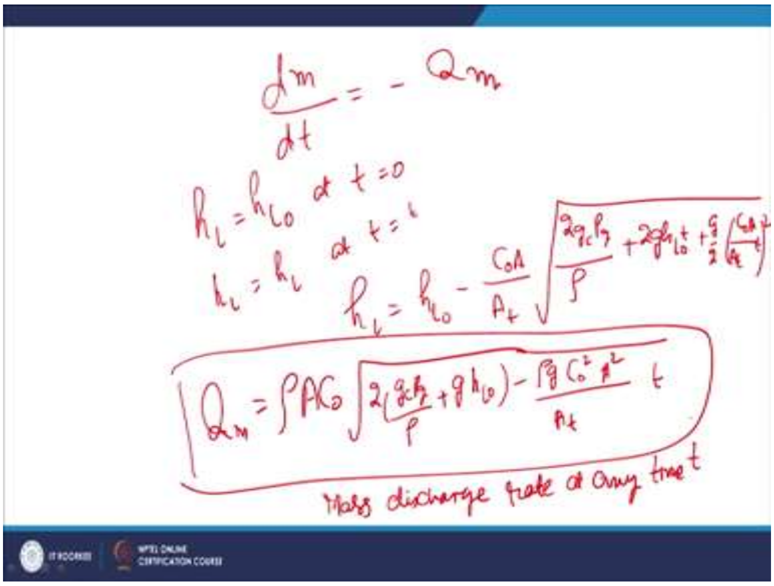

Now, let us have a look of rate of discharge, late of rate of change of mass. So, this is always having the time factor, so

$\frac{dm}{dt} = -Q_m$

Now, if we combine all the equations and integrate then you will find that

$h_L = h_{L0}$; at t = 0

$h_L = h_L$; at t = t

So, we can find out the liquid height level in the tank, so

$h_L = h_{L0} - \frac{C_0 A}{A_t}\sqrt{\frac{2g_c P_g}{\rho} + 2gh_{L0}t} + \frac{g}{2}(\frac{C_0 A}{A_t}t)^2$

So, mass discharge rate at any time t is given by

$$Q_m = \rho A C_0 \sqrt{2(\frac{g_c P_g}{\rho} + gh_{L0})} - \frac{\rho g {C_0}^2 A^2}{A_t} t$$

So, by this equation you can calculate the mass discharge rate at any time t.

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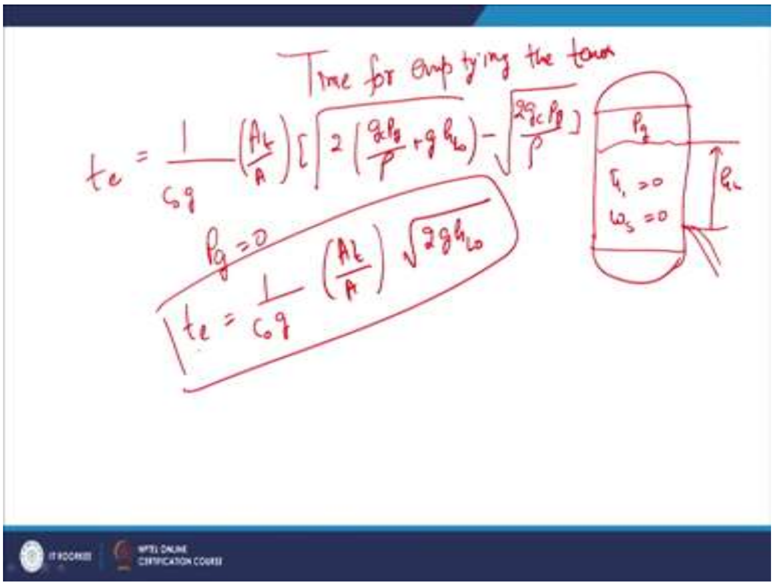

Now, let us have a look about the time for empty, emptying the tank. This is again, one of the thing which we need to discuss, how much time required to empty the tank? Again, let us have this tank in question. Now, here you are having the leak like this, this is the h_L u_1 bar is equal to 0, W_s is equal to shaft work is equal to 0, now this is the tank. Now, time for vessel to empty to the level of the leak you can determine by

$$t_e = \frac{1}{C_0 g}\left(\frac{A_t}{A}\right)[\sqrt{2\left(\frac{g_c P_g}{\rho} + g h_{L0}\right)} - \sqrt{\frac{2 g_c P_g}{\rho}}]$$

Now, if vessel is at atmospheric pressure then

$P_g = 0$

Then

$t_e = \frac{1}{C_0 g}\left(\frac{A_t}{A}\right)\sqrt{2 g h_{L0}}$

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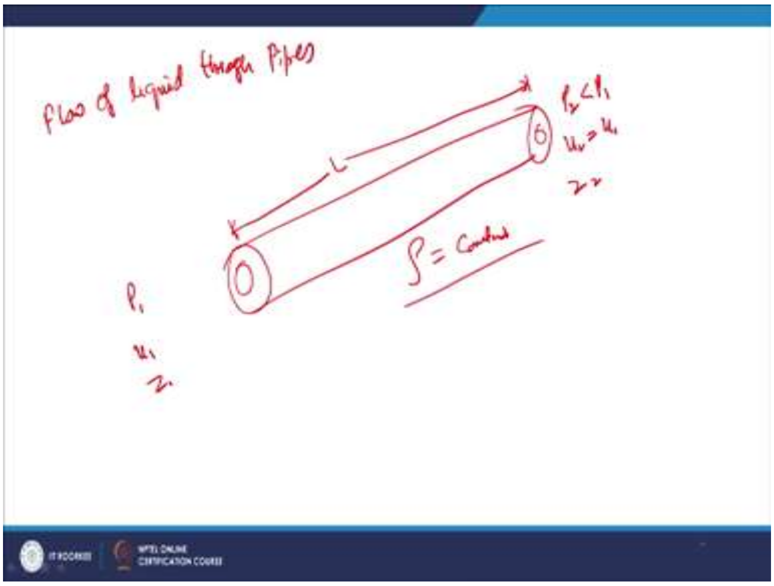

Now, let us consider another thing that is the flow of liquid through pipes. Now, here is a pipe like this which is having the length L, rho, let us take that rho is constant, through pipes, my initial conditions are P_1, u_1, Z_1 and the final conditions are P_2 is which is less than P_1 u_2 is equal to u_1 and Z_2, here we have taken this thing that "ρ" is constant. Now, let us take say that pipe transporting liquid is shown in the figure.

The liquid flows through the pipe due to the pressure gradient across the end of pipe. Now, there will be a definite amount of loss in pressure encountered due to the presence of frictional forces between the liquid as well as between the fluid and the valve of container. So, losses due to friction in long pipe are quite larger than the losses due to the bent and sudden enlargement and contraction in the fitting.

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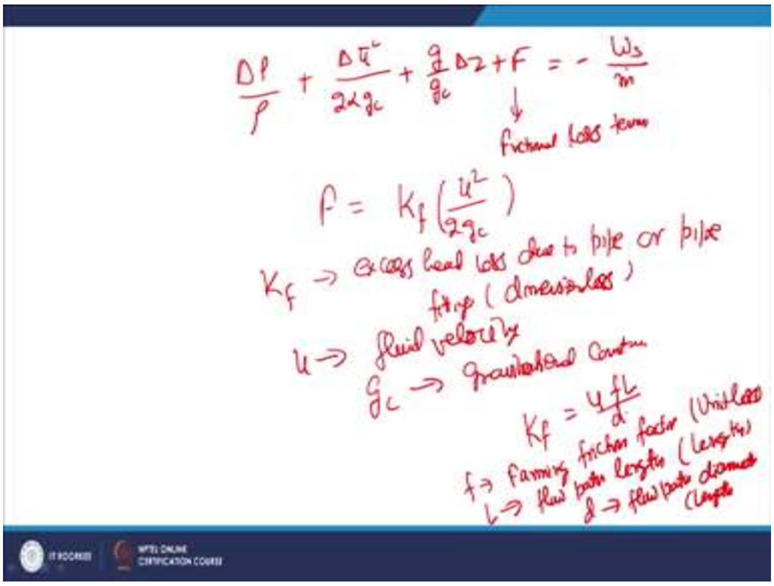

So, for incompressible fluid the mechanical energy equation can be written as

$\frac{\Delta P}{\rho} + \frac{\Delta \bar{u}^2}{2\alpha g_c} + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}$

Now, frictional loss term “F”, this is the frictional loss term, this includes the loss due to the flow through length of pipe, fittings such as various kind of fittings may take place like control valves, bends sometimes orifice, etcetera, pipe entrances and exit, there may be sudden expansion and contraction across the pipe.

So, there are so many things related to this one. So, we may calculate the friction loss F, like

$$F = K_f (\frac{u^2}{2g_c})$$

Where “K_f” is the excess head loss due to pipe or pipe fittings this is usually a dimensionless and “u” is the fluid velocity and “g_c” is of course our gravitational constant. So, excess head loss you can calculate through this particular equation that is

$$K_f = \frac{4fL}{d}$$

“F” is the fanning friction factor, factor which is all of course (unit less), “L” is the flow path, flow path length that is having the unit of length and “d” is the flow path diameter having the unit of length.

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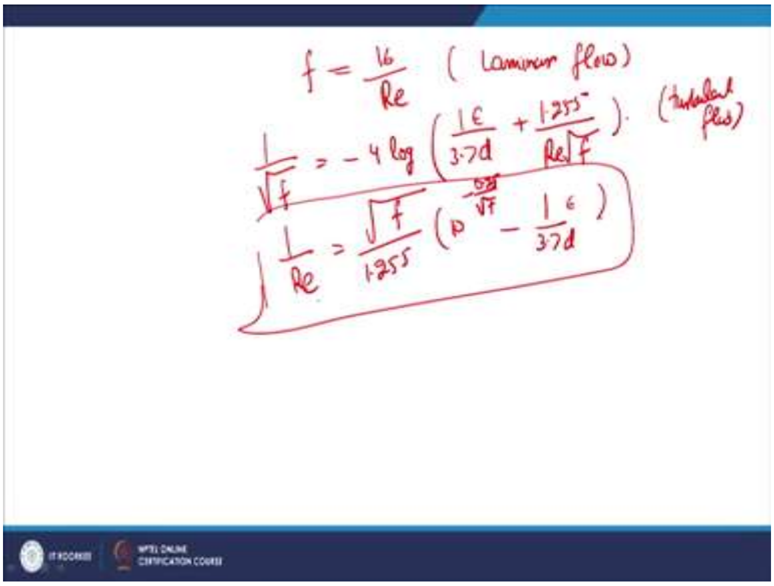

So, for a laminar flow, the fanning friction factor is given by

$$f = \frac{16}{Re}$$

Re is the Reynolds number that is for the laminar flow regime, and for the turbulent flow it is given as

$$\frac{1}{\sqrt{f}} = -4\log(\frac{1}{3.7}\frac{\varepsilon}{d} + \frac{1.255}{Re\sqrt{f}})$$

So

$$\frac{1}{Re} = \frac{\sqrt{f}}{1.255}(10^{-\frac{0.25}{\sqrt{f}}} - \frac{1}{3.7}\frac{\varepsilon}{d})$$

Now, in this particular table you can have a look of various roughness factors epsilon for the clean pipe.

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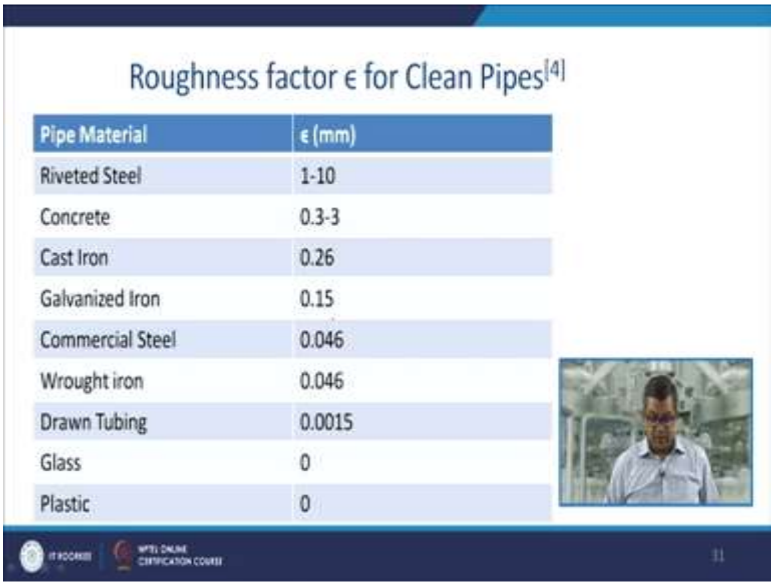

So, in this particular table, we have enlisted different type of pipe materials with different roughness factors like Riveted steel, it is having the roughness factor of 1 to 10 mm, Concrete 0.3 to 3, Cast iron 0.26, Galvanized iron 0.15, Commercial steel 0.046, Wrought iron 0.046, Drawn tubing 0.0015, in glass the roughness factor is 0 and the plastic the roughness factor is 0.

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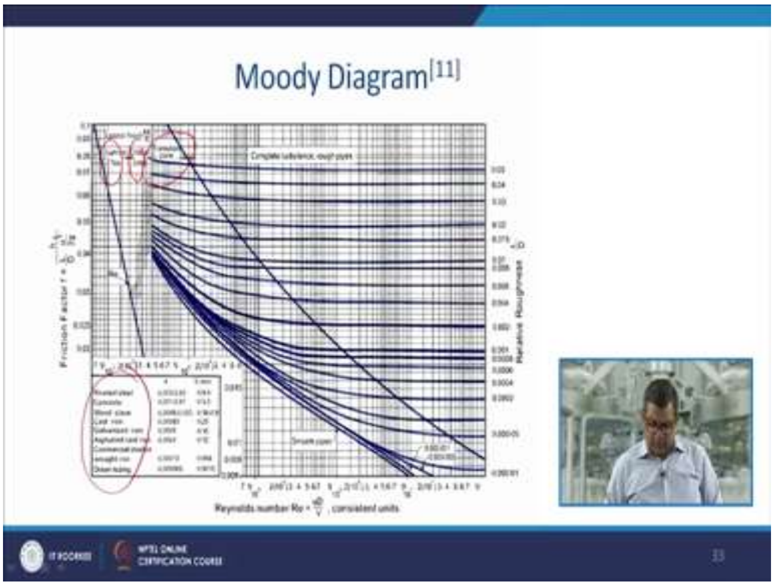

Now, here is the Moody's diagram, which tells you about the, this is a depiction of a relative roughness factor epsilon by d with respect to the Reynolds number that is Re u upon d with the friction factor F. So, you can have a different you can calculate or you can find out based on your material in question then you can find out the friction factor either with the help of a

Reynolds number and relative roughness with the different zones like laminar, critical zone, transition zones.

So, you can you can easily find out the things which you may require in due course of time for calculating the friction factors. Now, in the next aspect we are going to discuss. for the fully developed flow, that is F used for fully developed flow, the F is independent of Reynolds number.

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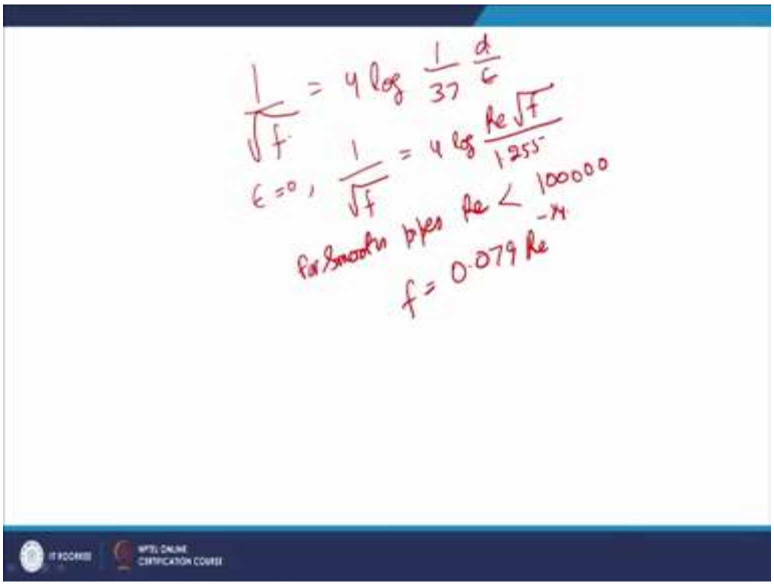

So,

For fully developed flow, *f* is independent of *Re*

$$\frac{1}{\sqrt{f}} = 4\log\frac{1}{3.7}\frac{d}{\varepsilon}$$

Now, if we take the smooth pipe which we have enlisted previously, so

For smooth pipes, ε=0

$$\frac{1}{\sqrt{f}} = 4\log\frac{Re\sqrt{f}}{1.255}$$

Take the help of the previous slides. Blasius approximation. Now, we may take the Blasius' approximation for this Blasius' approximation you can refer on the references,

For smooth pipes with Re< 100 000

$$f = 0.079\, Re^{-1/4}$$

Now, while considering the flow of a liquid through pipes, let us take the 2-K or Hooper model.

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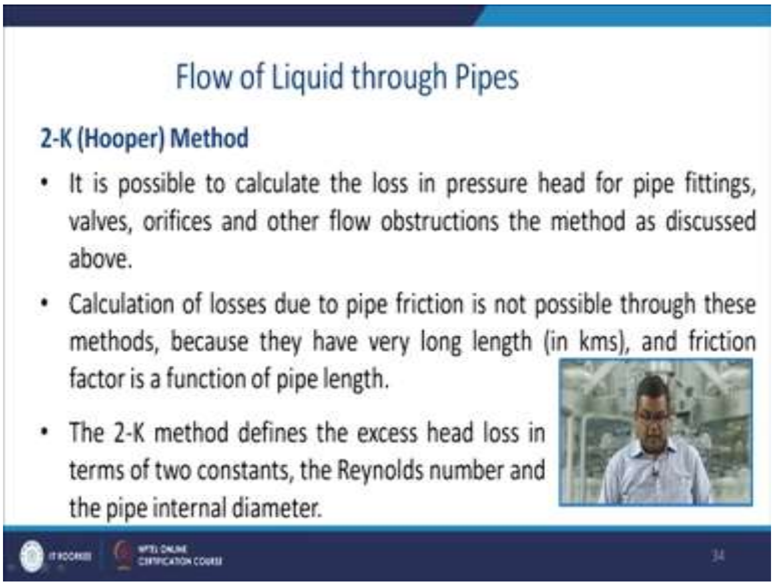

Now, it is possible to calculate the loss in pressure head for pipe fitting, valve, orifice and other flow obstructions, this is the method (apply) applies for this one. The calculation of losses due to the pipe friction is not possible through these methods because they have a very long length of even in kilometres and the friction factor is a function of pipe length. So, in 2-K model defines the excess head loss in terms of two constant that is Reynold number and the pipe internal diameter.

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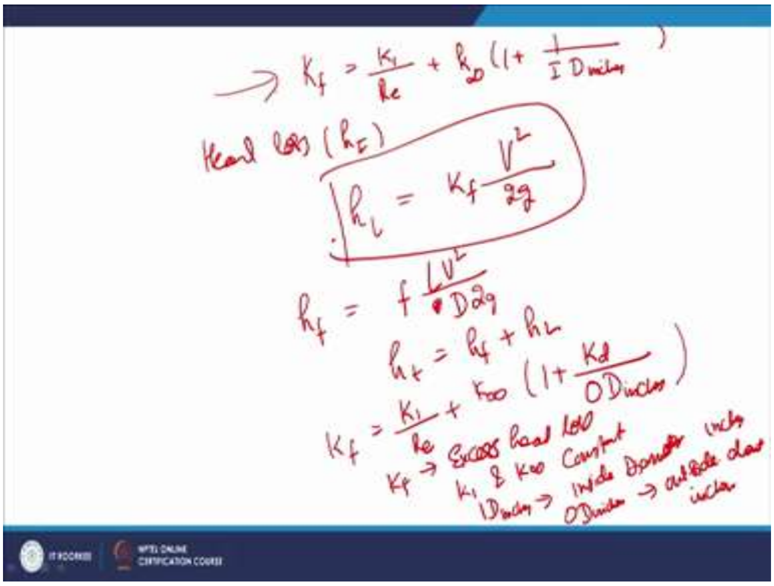

So, when we have this this particular aspect in consideration then we may have this

$$K_f = \frac{K_1}{Re} + k_\infty(1 + \frac{1}{ID_{inches}})$$

Now, head loss h_l through the fitting can be calculated by the determining the value of K_f from this equation and using it to the this equation that is

$$h_l = K_f \frac{V^2}{2g}$$

Now, head loss through pipe friction which you can calculate by

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

So, the total head loss would be

$$h_t = h_f + h_l$$

Now, if we apply the 3-K Darby method, so in this method

$$K_f = \frac{K_1}{Re} + k_\infty \left(1 + \frac{K_d}{OD_{inches}}\right)$$

Now, here K_f is the excess head loss, k_1 and k_∞ they are constant, ID is the in the inside diameter which is in inches, OD is the outside diameter in inches, so you can calculate this K_f by this method.

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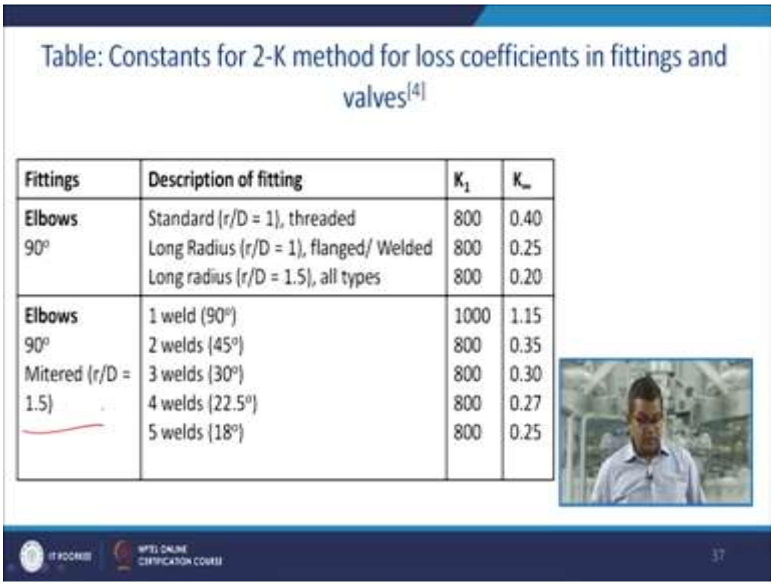
Table: Constants for 2-K method for loss coefficients in fittings and valves[4]

Fittings	Description of fitting	K_1	K_∞
Elbows 90°	Standard (r/D = 1), threaded	800	0.40
	Long Radius (r/D = 1), flanged/ Welded	800	0.25
	Long radius (r/D = 1.5), all types	800	0.20
Elbows 90° Mitered (r/D = 1.5)	1 weld (90°)	1000	1.15
	2 welds (45°)	800	0.35
	3 welds (30°)	800	0.30
	4 welds (22.5°)	800	0.27
	5 welds (18°)	800	0.25

Now, in the next table this one, we can and we have enlisted the constant for 2-K method for loss coefficient in fittings and valves, so there are multiple type of fittings like elbow which is having a 90 degree angle and description of fitting that it is a standard r by D is equal to 1, threaded and K_1 is 800 and K infinity is 0.40. Long radius r/D equal to 1 flanged or welded 800 and 0.25, long radius that is r/ D equal to 1.5 and all types of things are clubbed under this head, so K_1 is equal to 800 and 0.20 is K_∞.

Similarly, for elbow which has a (meet) mitered at r/ D equal to 1.5, 1 weld 90 degree, 1000, 1.15, 2 welds 45 degree, it is 800 or point K_∞ is 0.35, 3 welds 30 degree, 800, 0.30 K_∞, 4 welds 22.5 degree and that is 800 and 0.25 and 5 welds 18 degree that is 800 is K_1 and 0.25 is K_0.

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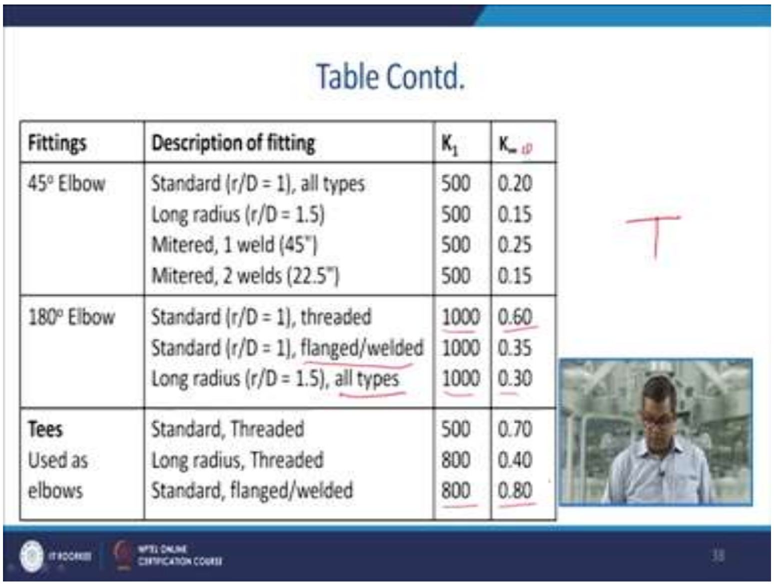

Table Contd.

Fittings	Description of fitting	K_1	K_∞
45° Elbow	Standard (r/D = 1), all types	500	0.20
	Long radius (r/D = 1.5)	500	0.15
	Mitered, 1 weld (45°)	500	0.25
	Mitered, 2 welds (22.5°)	500	0.15
180° Elbow	Standard (r/D = 1), threaded	1000	0.60
	Standard (r/D = 1), flanged/welded	1000	0.35
	Long radius (r/D = 1.5), all types	1000	0.30
Tees Used as elbows	Standard, Threaded	500	0.70
	Long radius, Threaded	800	0.40
	Standard, flanged/welded	800	0.80

Similarly, if we have 45 degree elbow that is standard r/ D is equal to 1 for all types, K_1 is 500 and K_∞ is 0.20, long radius we may have a certain things related to the long radius r/ D is equal to 1.5, so 500 is K_1 and 0.15 is K_∞ then 180 degree elbow the standard r/ D is equal to 1 maybe threaded, so 1000 is the K_1 and 0.60 is K_∞. Similarly, standard r/ D equal to 1 that is flanged or welded that is 1000 and 0.35 is the K_∞ and long radius for all types that is r/ D is equal to 1.5, K_1 is 1000 and 0.30 is K_∞.

There are various Tees, Tess are like this used as sometimes used as elbow, the standard, threaded may be long radius may be threaded, standard, flanged or welded. So, they are having the respective range of K_1, K_∞ like 500 to K and K_∞ is 0.70 then 800 is a K_1 and 0.40 is the K_∞ and 800 is standard, flanged or welded for this we are having the 800 is K_1 and K_∞ is 0.80.

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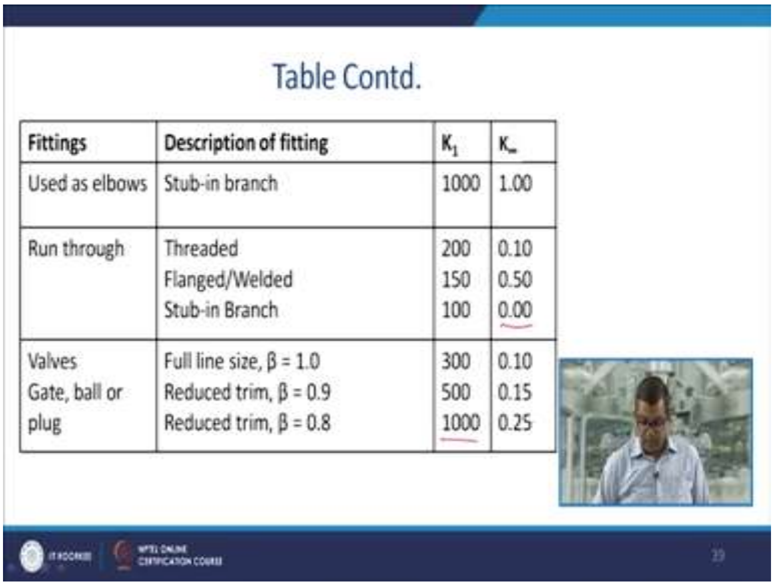

Similarly, sometimes fittings they are used as a elbow that is Stub-in branch, so K_1 is for them the K_1 is 1000 and K_∞ is the 1,0 sometimes they are certain run through fittings they are threaded 200, 0.1, flanged or welded 150, 0.5, Stub-in branch they may be 100 and none, sometimes valves may be gate, valve or a plug. The full length size beta is equal to 1.0 and a K_1 is 300 and K_∞ is 0.1, reduced trim 500 and 0.15, reduced trim beta is equal to 0.8 for this this the K_1 is 1000 and K_∞ is 0.25.

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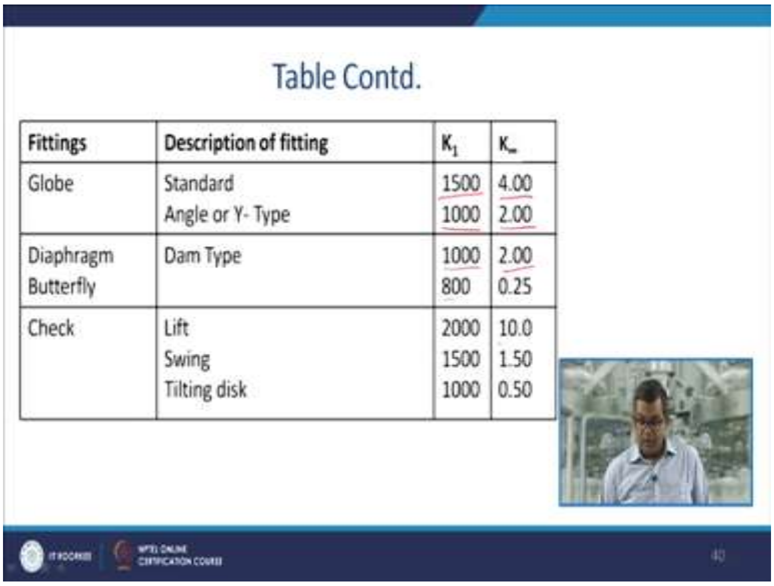

Then there are certain fittings related to the globe then the standard, for the standard the K_1 is 1500 and K_∞ is 4 then angle or gamma type, then K_1 is equal to 100 and K_∞ is 2. There are diaphragm and butterfly, the dam type of description of the fitting is dam type, then for this

1000 to 2 is infinite K_∞ 800 and K_∞ is 0.25. Check valve maybe left 2000 to 10, swing 1500, 1.5 and tilting disk 1000 to and K_∞ is 0.5.

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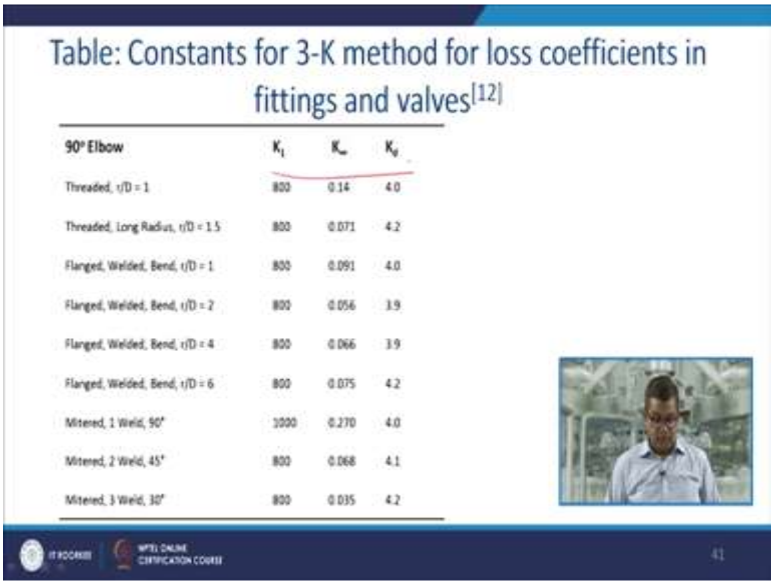

Now, this particular table enlisted the constants for 3-K method of loss for loss coefficient in fitting and you can have a look of all kind of 90 degree elbow that is threaded, threaded long radius, flanged, etcetera and their respective values in terms of K_1, K_∞ and K_d. So, for your reference you can always use this particular aspect.

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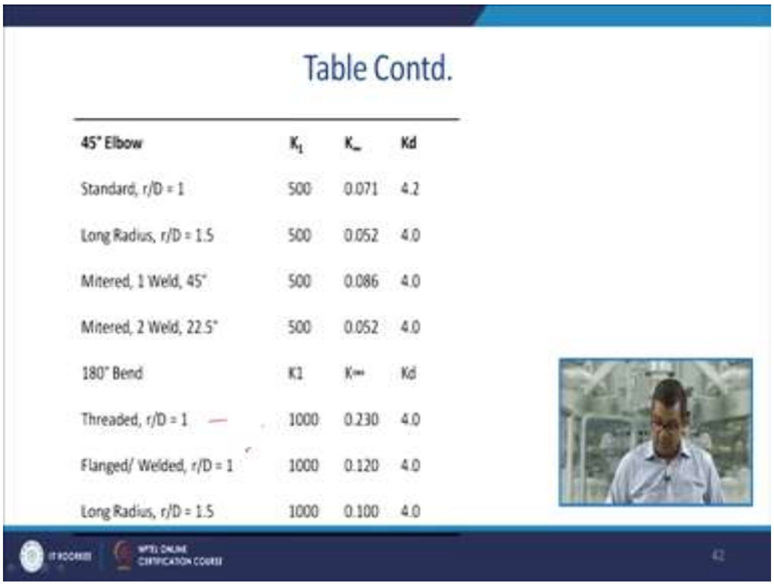

And here in this particular table the 45 degree elbow is enlisted with respect to the K_1, K_∞ and K_d. The standard, long radius, etcetera, threaded, flanged and different descriptions likewise.

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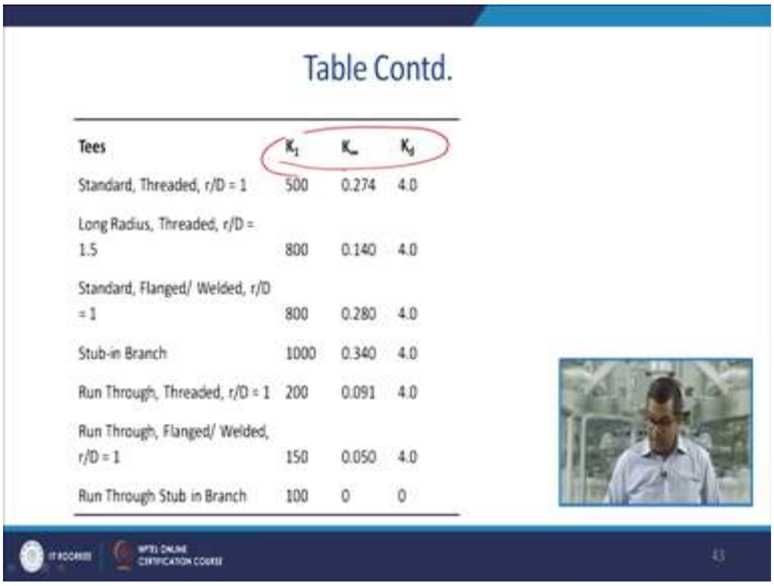

In this particular table, you can have a look of different type of Tees, like the standard, long radius, etcetera and their respective K_1, K_∞ and K_d values.

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Now, in this slide we have the different valves like angle valve, globe valve, plug valve, gate valve, ball valve, butterfly by valve, swing valve, lift check valve and the values of K1, K_∞ and K_d. So, in this module we have discussed different aspects of source model and specially applicable for the liquid and liquid system. So, we have discussed the flow of liquid through a small hole, cracks, etcetera.

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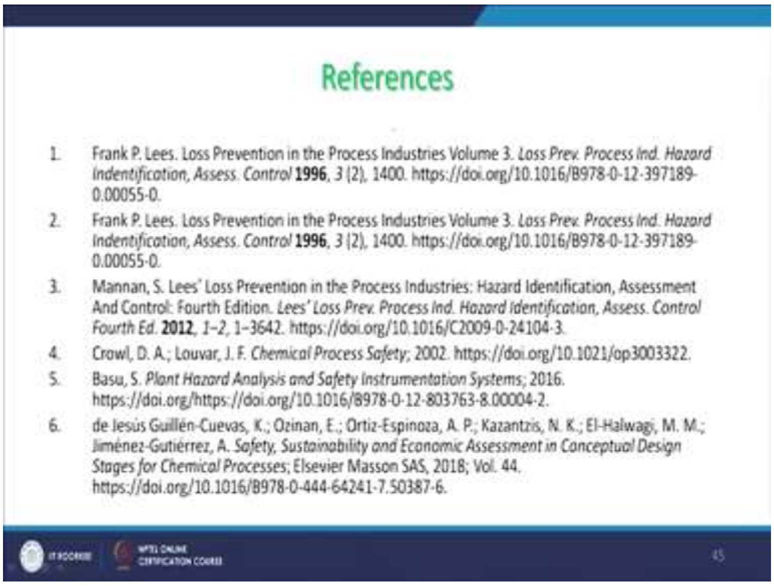

And in case of further referencing, you can have a look of various references which are listed in this particular slides and hopefully this particular information is useful for you, thank you very much.