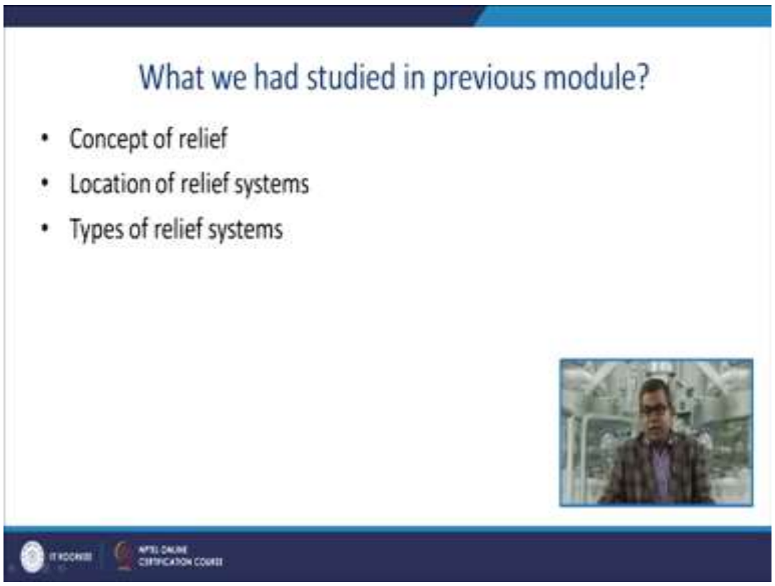
Chemical Process Safety
Professor Shishir Sinha
Department of Chemical Engineering
Indian Institute of Technoloy, Roorkee
Lecture 35
Relief Scenario

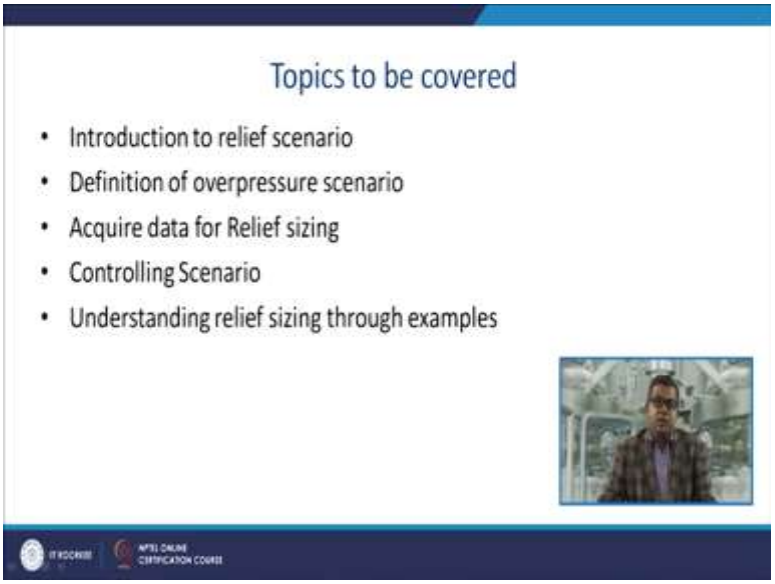
Welcome to the next module of Relief. In this particular module which is as the name implies that we will discuss about the Relief Scenario.

(Refer Slide Time: 00:42)



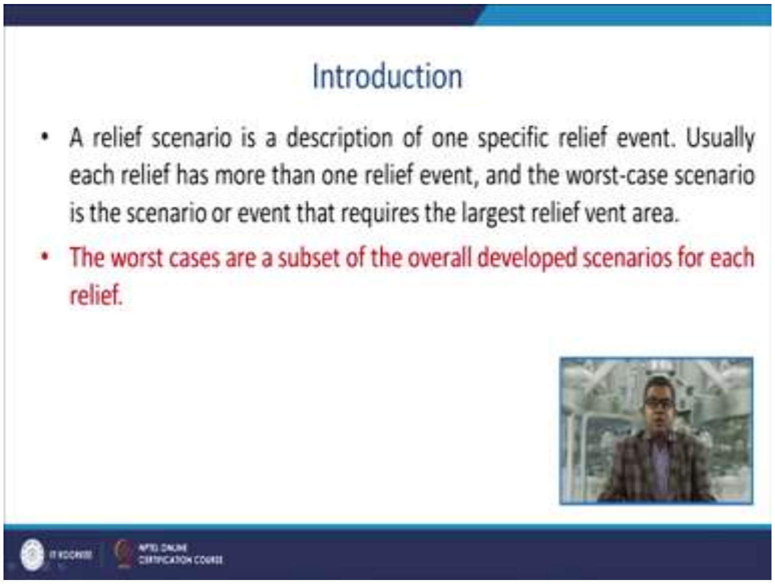
Now, have a look that what we had studied in the previous module. We had the discussion about the concept of relief. What is the different subsets of this relief? We had a discussion about the location of relief system to be employed and the previous module we have discussed the various type of relief system applicable in the chemical process industry. Now, in this particular module, we are going to discuss about the introduction to relief scenario. What kind of different scenario are there? How we can handle all those things? So we will discuss about these relief scenario in this particular module.

(Refer Slide Time: 01:18)



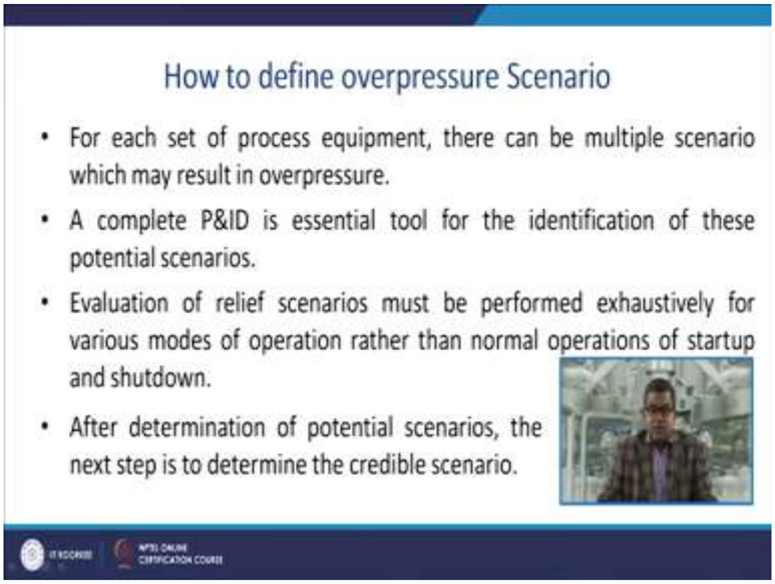
Will have a definition of overpressure scenario as an example, how to acquire the data for various relief sizing, this is again a very core issue which we are going to discuss in this particular module. How we can control the scenario? That is the controlling scenario aspect. We are going to discuss. Will understand about the relief sizing through example. We will have a couple of example in this particular module and a subsequent module. So, we will discuss about all those things in this particular module. Now, first thing is that, what is a relief scenario? We must know because before we address this particular problem.

(Refer Slide Time: 02:03)



So the standard definition of relief scenario is a description of one specific relief event. Now, usually each relief event or each relief has more than one relief event and the worst-case scenario is the scenario or event that requires the largest relief vent area. So this is the standard definition of a relief scenario. Now, the worst case is because we will frequently use this worst-case terminology and in the previous definition we have already discussed the worst case scenario. So the worst cases are a subset of overall developed scenario for each relief. So you must remember this particular line in subsequent study.

(Refer Slide Time: 02:58)



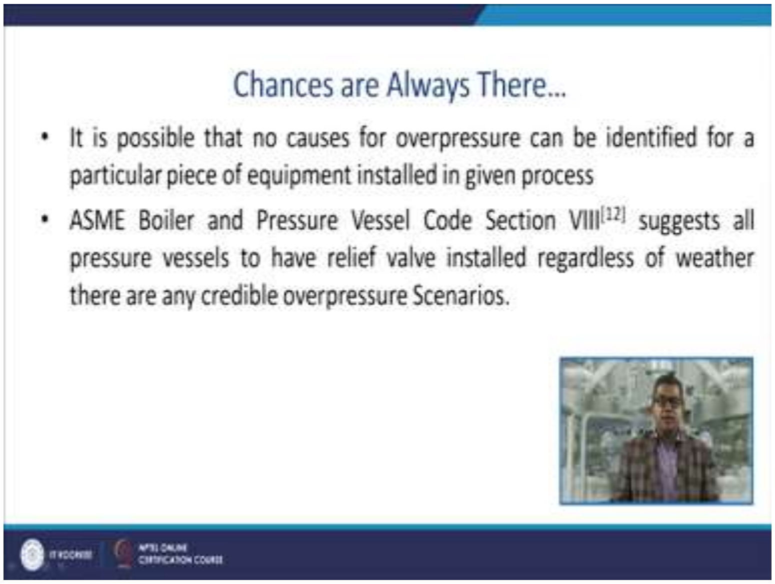
Now, question arises that how to define the overpressure scenario? So for each set of process equipment, there can be multiple scenario which may result in various kind of over pressure and sometimes because of the process requirement, sometimes because of the certain failures there may be scenario of overpressure. So, a complete P&ID diagram is essential tool for identification of these potential scenario. It provides you a very helpful tool.

Now, evaluation of relief scenario must be performed exhaustively for various mode of operation rather than the normal operation of startup and shutdown. So the proper knowledge of P&ID diagram is extremely important while you are evaluating the relief scenario. So after determining the potential scenario, the next step is to determine the credible scenario.

(Refer Slide Time: 03:55)

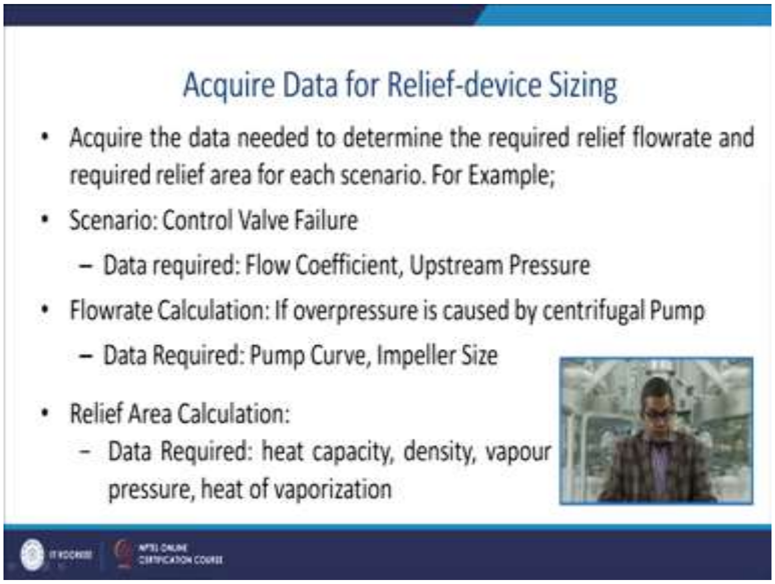
Now, a scenario that involves a single failure is called the credible scenario. So while we are considering different subsets this particular recordable scenario gives a very good impetus to the analysis. Now a scenario having multiple independent failure are typically not considered for sizing of individual relief device. So, therefore, the credibility is also the function of probability and consequences. Now, we can do the risk assessment through a various modes, one is the layer of protection analysis and sometimes it is referred as LOPA then we may have a hazard and operability analysis referred as the HAZOP. We may have a fault-tree analysis sometimes referred as a FTA then we may have a failure mode and effective analysis FMEA.

(Refer Slide Time: 04:57)



Now, it is possible that no cause for over pressure can be identified for a particular piece of equipment installed in a given process. So, ASME boiler American Society for Mechanical Engineers, so they have developed the various codes. So ASME boiler and pressure vessel code section 8 suggests that all pressure vessels, all pressure vessels to have relief valve installed regardless of whether there are any credible overpressure scenario or not? So, it is mandatory for all boiler and that is why in Indian context we are having the separate boiler certification code.

(Refer Slide Time: 05:43)

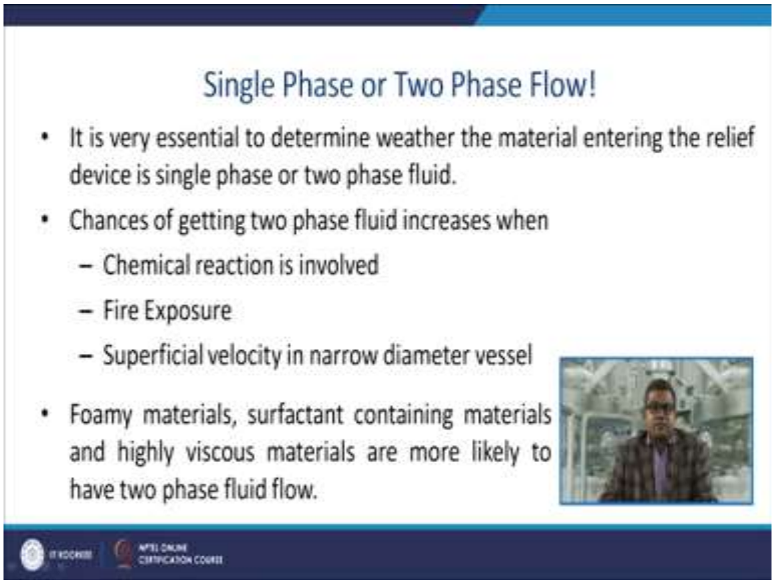


Now, next aspect is that acquiring data for various relief device sizing. So, acquiring data needed to determine the required relief flowrate and a required relief area for each scenario. So we have developed a scenario, then we must know or we must acquire the relevant data for devising, for relief device sizing. Now, there are a couple of examples like scenario 1 is the control valve failure.

Now for this the data required that is the flow coefficient, upstream pressure, etc. So once you determine all these things then the flowrate calculation. So if over pressure is caused by centrifugal pump just for the sake of an example then again the data required is the pump curve, impeller size or other classification or statistical data for that centrifugal pump.

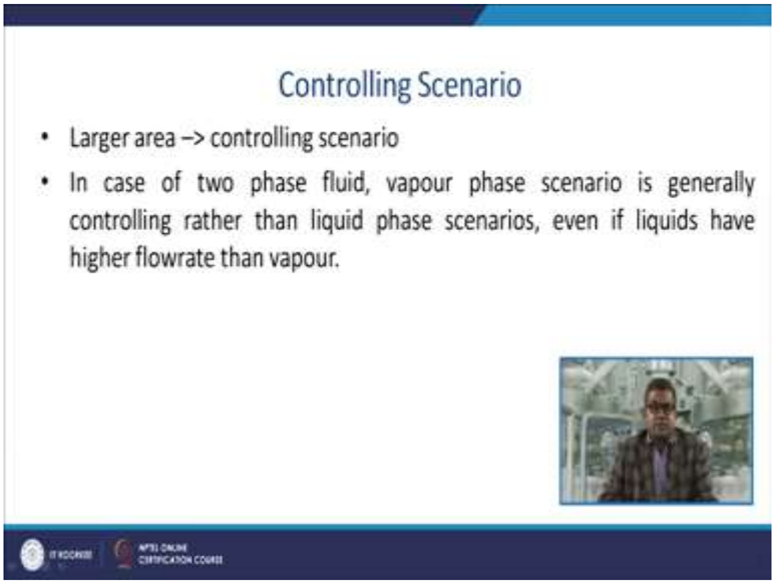
Then you need to require the calculation, perform the calculation of relief area and once you are intended to go for this one, then the data required are heat capacity, what is the heat capacity of the fluid in question, then the density, the vapor pressure, the heat of vaporization so various (thermo) or other thermodynamic data?

(Refer Slide Time: 07:07)



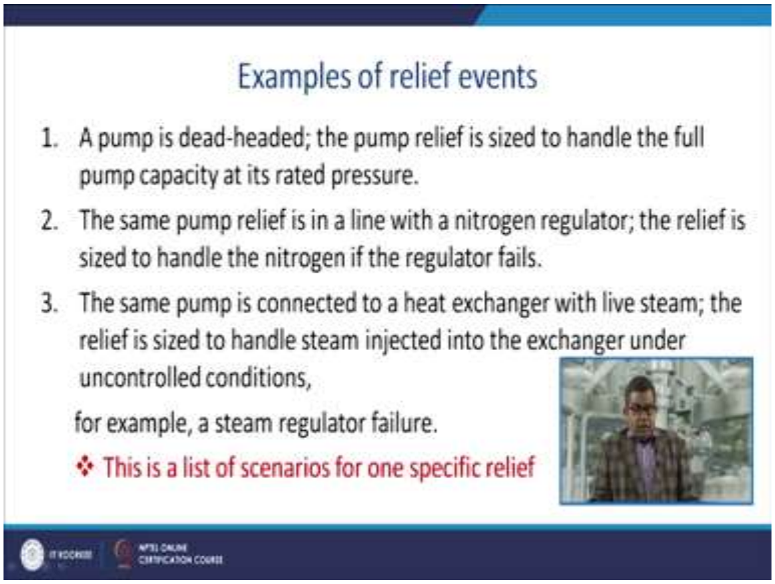
Then we may have to look into the single phase or a two phase flow. Now, it is very essential to determine whether the material entering to the relief device is under the single phase or a two phase operation or it is a single phase or a two-phase fluid. Now, chances for getting two phase fluid increases when there is a chemical reaction involved or something is going on which is in the intermediate phase, there may be chances of fire exposure, superficial velocity in the narrow diameter vessel, then there may be chances of phase transformation. Then, the foamy materials, surfactant containing materials and highly viscous material they are more likely to have two phase flow.

(Refer Slide Time: 07:55)



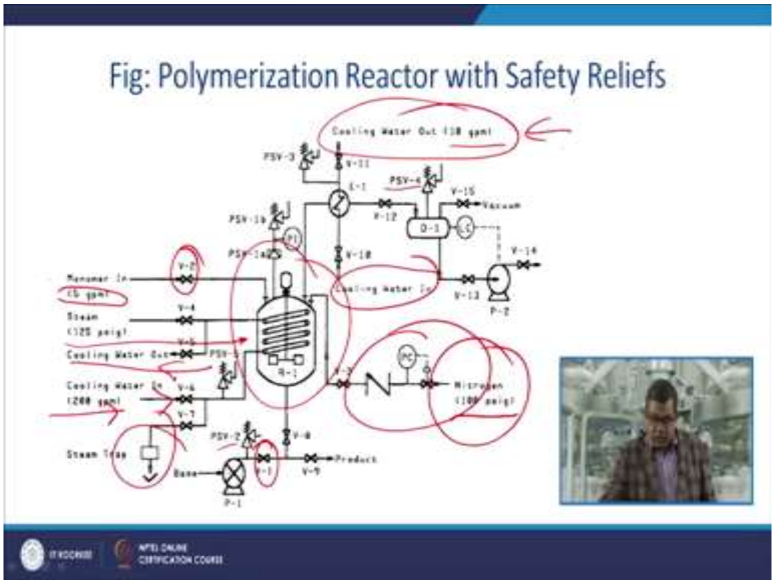
Then we have to discuss about the controlling scenario. Remember, whenever we are having the larger area then the controlling scenario come into the picture. So in case of two phase (flow) fluid vapor phase scenario is generally controlling rather than liquid phase scenario, even if liquid have higher flow rate than the vapor one.

(Refer Slide Time: 08:21)



Now, let us have a couple of example for the relief event. Now, a pump is dead-headed, the pump relief size to handle the full pump capacity at its rated pressure. Now the same pump relief is in line with a nitrogen regulator, the relief sized to handle the nitrogen if the regulator fail, so this is one of the example. Now if the same pump is connected to the heat exchanger with the live stream, the relief is sized to handle steam injected into the exchanger under uncontrolled condition. So you can analyze all these three things when the pump is same but the media is different. So, if the steam regulator failure, then this is a list of scenario of one specific relief. Now remember the relief is same, the pump is same but the media is different.

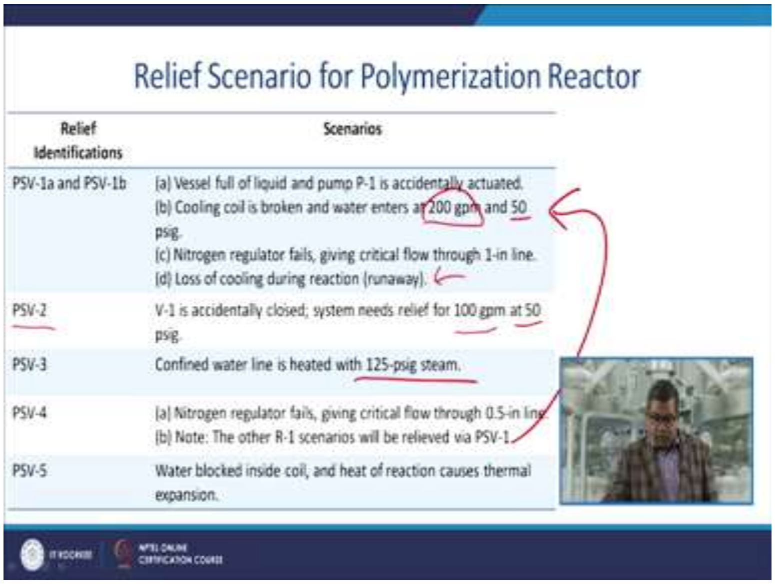
(Refer Slide Time: 09:21)

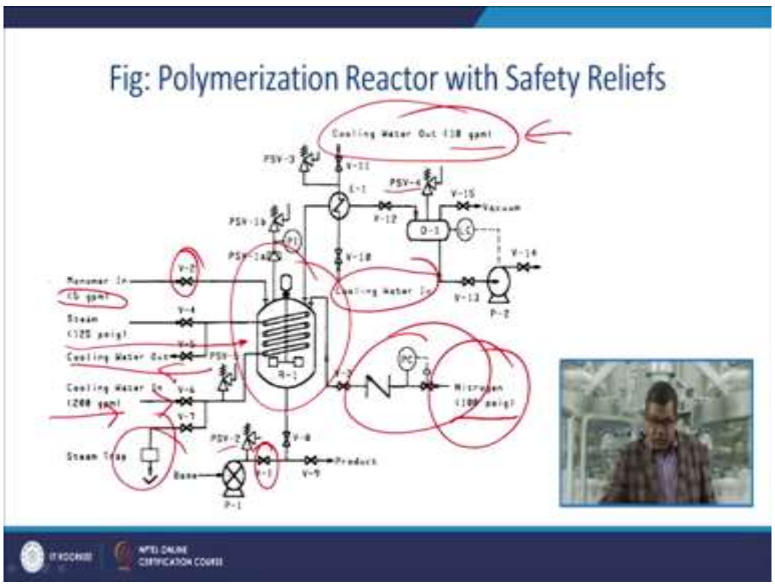


Another is the polymerization reactor with a safety relief. Now, here you are having a polymerization reactor with monomer, the quantity is given that how much the flowrate, this is a valve. Now steam injection, the cooling water out, the cooling water in, so you are having 1, 2, 3, 4 different media, there is an steam trap. Here the nitrogen purging is given to it and this particular reactor is operating under vacuum.

So the cooling water outlet is this one, so and this one is the cooling water in. So it is quite simple, you are having one polymerization reactor with the monomer specified quantity of the monomer, this is the steam heated with the cooling water as a cooling media. Obviously, we are assuming that this is an exothermic reaction. It is equipped with the different pumps and steam traps.

(Refer Slide Time: 10:30)



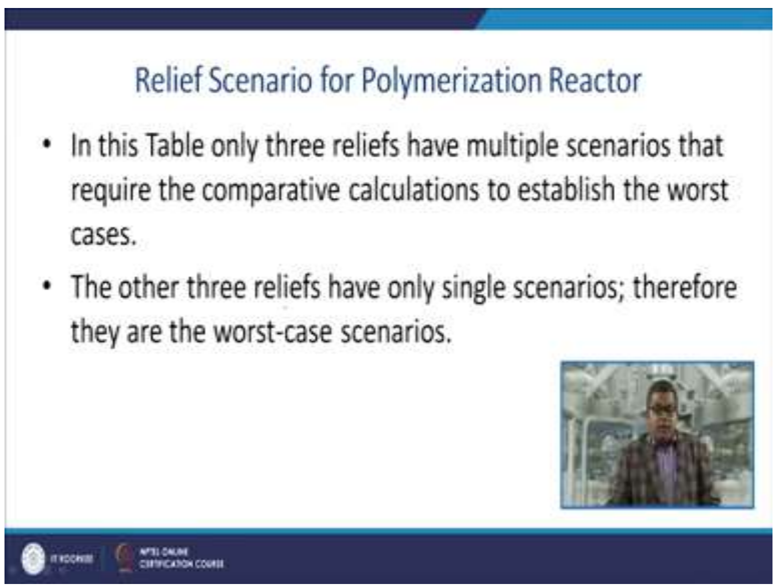


Now this is the relief scenario for this particular polymerization reactor. Now if you go for this particular reactor, this is the PSV 1A and PSV 1B (V), these are the safety valves, different safety valves. Now vessel full of liquid and pump p1 is accidentally actuated, this may be one scenario. Sometimes it may happen that the cooling coil is broken and water enters at around this particular specific quantity and this particular pressure.

Sometimes it may happen that the nitrogen regulator, this one, the nitrogen regulator fails giving the critical flow through one in line. Sometimes it may happen that loss of cooling because we are having two cooling jackets, two cooling devices. So sometimes it may happen that the loss of cooling during the reaction then it may proceed towards the runaway reaction. Another scenario, the relief identification is the PSV 2, now valve 1 is accidentally closed.

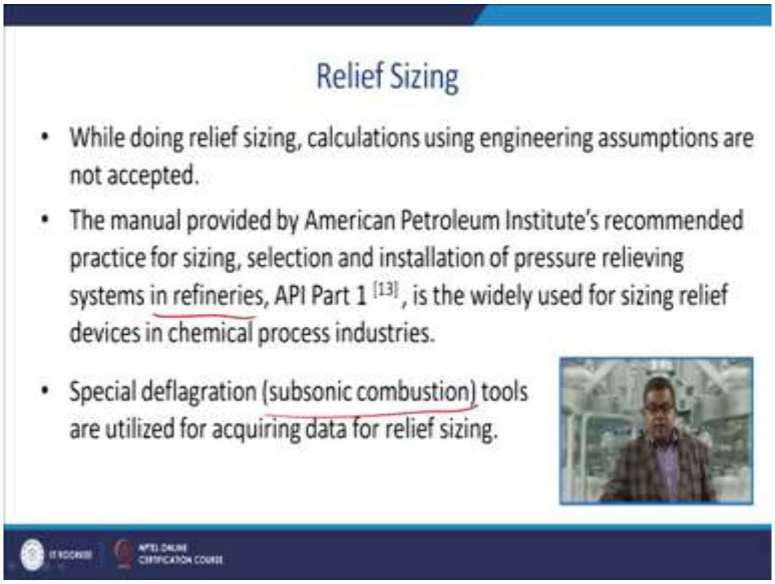
Now, the system needs relief for this particular quantity at this one because this is operating requirement. Then another scenario that confined water line is heated with 125 PSIG steam here you can see this is valve 1. Another PSV 4 is that nitrogen regulator fails giving the critical flow through 0.5 inch line this one. Now the other reactor one scenario will be relieved via this PSV-1. Another scenario is the PSV-5 that water blocked inside the coil, sorry, see these are the coils. So water blocked inside the coil and heat of reaction causes the thermal expansion. So these are the various relief scenario.

(Refer Slide Time: 12:47)



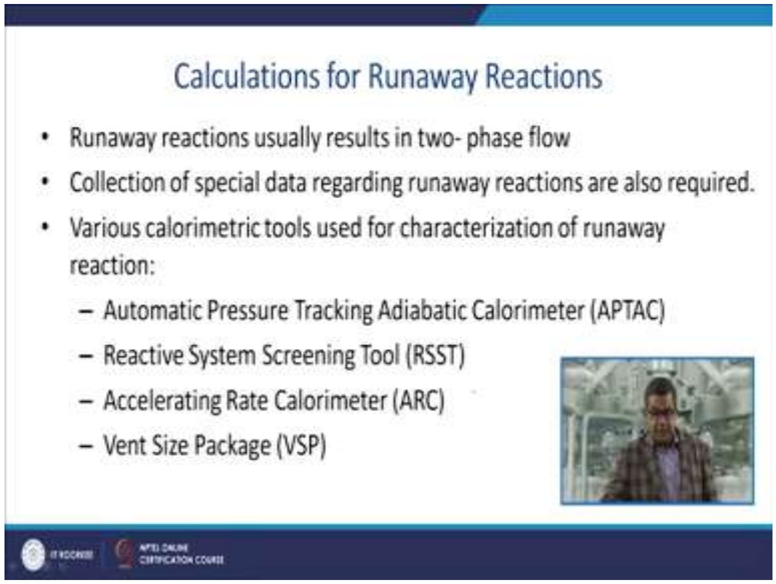
Now in this table only three relief have the multiple scenario. Now you can see, the three reliefs have the multiple scenario that require the comparative calculation to establish the worst case, the other three reliefs have only a single scenario. Therefore, they are again the worst case scenario.

(Refer Slide Time: 13:17)



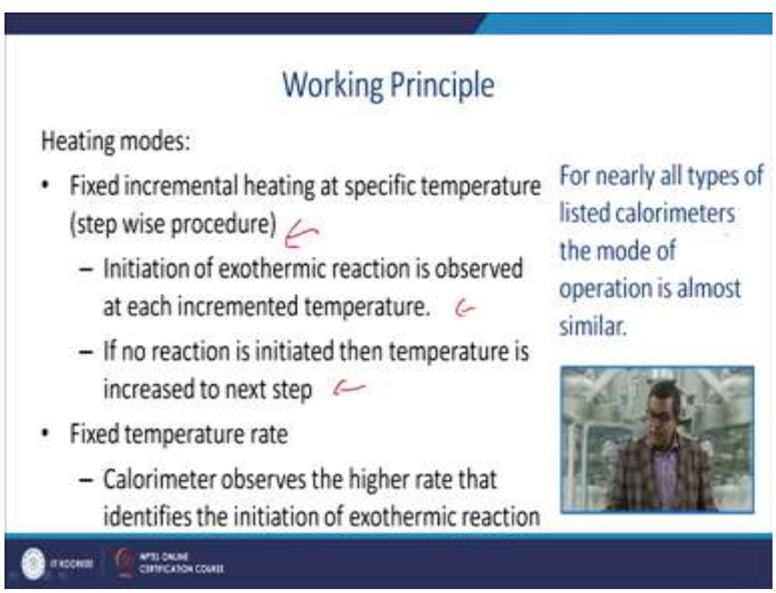
So while we consider the relief sizing calculation using the engineering assumptions are usually not accepted because we are having a practical scenario. So the manual provided usually by American Petroleum Institute, API, recommended the practice for sizing. The selection and installation of various pressure relieving system in various refineries. So we have given one reference for this API part 1 and which is widely used for sizing relief devices in various chemical process industries. Remember refineries they are working under the extreme conditions. Now special deflagration or sometimes referred to as a subsonic combustion. This deflagration tools they are utilized for acquiring data of relief sizing.

(Refer Slide Time: 14:03)



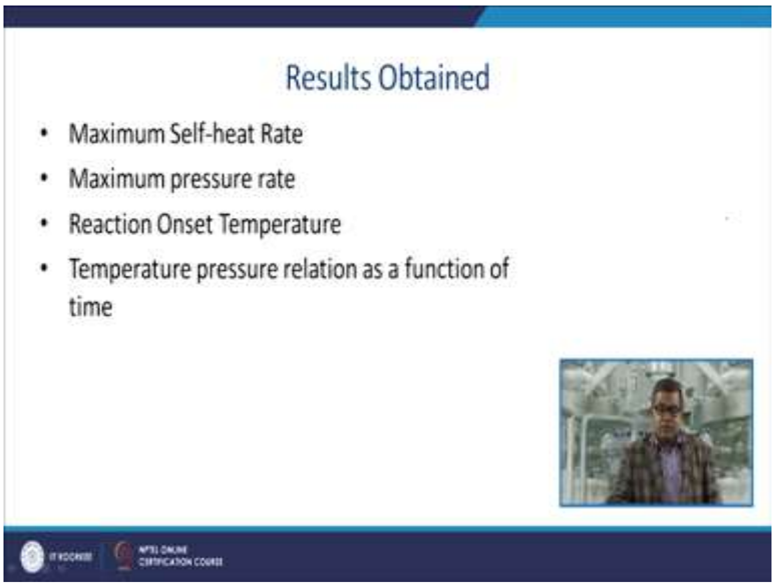
Now, next thing is that the calculation of a runaway reaction. So usually runaway reactions results in two-phase flow, the collection of special data regarding runaway reactions are also required. So the quality and the scope of these data depends on what kind of process you are using. Now various calorimetric tools used for characterization of runaway reaction. Now, these are like Automatic Pressure Tracking Adiabatic Calorimeter APTAC. Now, Reactive System Screening tools are SST, Accelerating Rate Calorimeter ARC, Vent Size Package VSP.

(Refer Slide Time: 14:47)



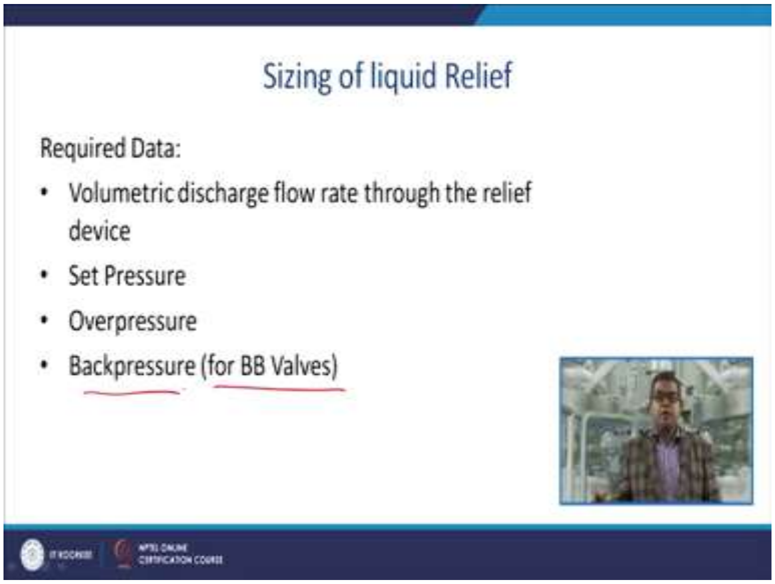
Now there are several working principles involved in these sizing. Now, one is the heating mode that is the fixed incremental heating at a specified specific temperature that is the step wise procedure. So, the initiation of exothermic reaction is observed in each incremented temperature, this is for the data collection. Now, if no reaction is initiated, then the temperature is increased to the next step. So this is the heating mode methodology. Sometimes you may have a fixed temperature rate, so the calorimeter observes the higher rate then identifies the initiation of exothermic reaction. So for all, for nearly all type of listed calorimeters in the mode of operation is almost similar.

(Refer Slide Time: 15:42)



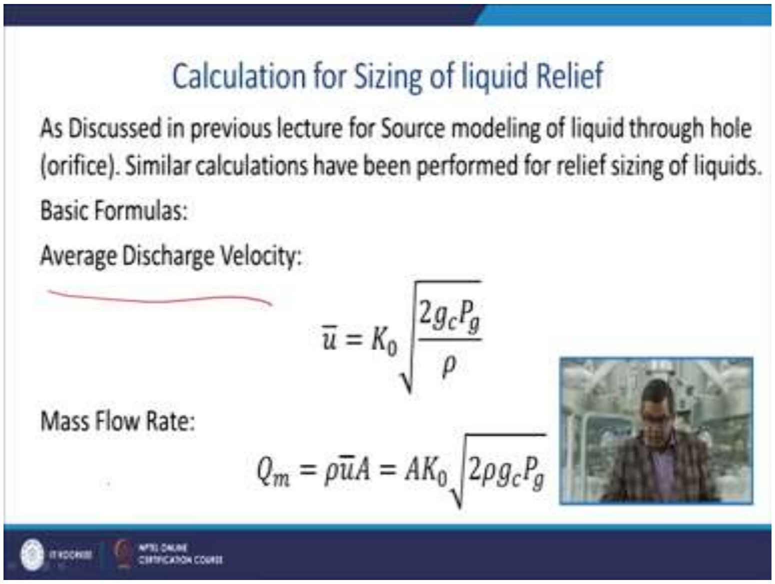
Now, the result obtained under this, the maximum self-heat rate, you may have to discuss the maximum pressure rate, the reaction on set temperature and the temperature pressure relation usually as a function of time.

(Refer Slide Time: 15:59)



So, whenever we perform the sizing of liquid relief, we are required various set of data that the volumetric discharged flow rate through the relief device that depends on the opening of the relief device. What is the set pressure of that relief device? What is the due consideration of the overpressure in question or were pressure in the process? And we need to consider back pressure especially for BB valves.

(Refer Slide Time: 16:33)



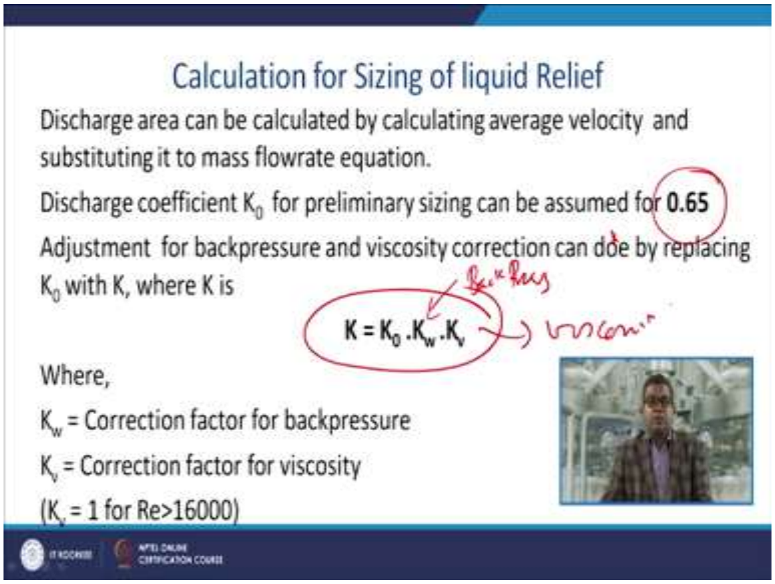
So while performing the calculation for sizing of liquid relief, we have already discussed in the previous lecture of various source model of liquid through different openings or holes or orifice. The similar calculations have been performed for relief sizing of liquid. So the basic formula is almost same. Now, here we have the average discharge velocity that is

$$\overline{u} = K_0 \sqrt{\frac{2g_c P_g}{\rho}}$$

and the mass flow rate, which we have already discussed in the separate modules earlier, that is

$$Q_m = \rho \overline{u} A = A K_0 \sqrt{2\rho g_c P_g}$$

(Refer Slide Time: 17:25)

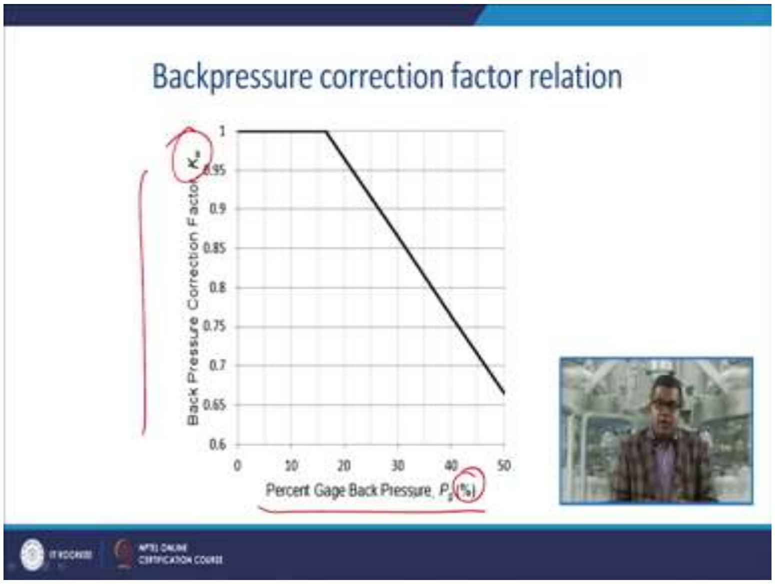


So the discharge area you can calculate by calculating the average velocity. It is a normal fluid dynamics phenomena, the average velocity and substituting it to the mass flow rate equation. Now this K naught is the discharge coefficient for the preliminary sizing, this can be assumed to be at 0.65. So adjustment for the back pressure and velocity correction can be done by replacing K_0 with K, where

$K = K_0 .K_w .K_v$

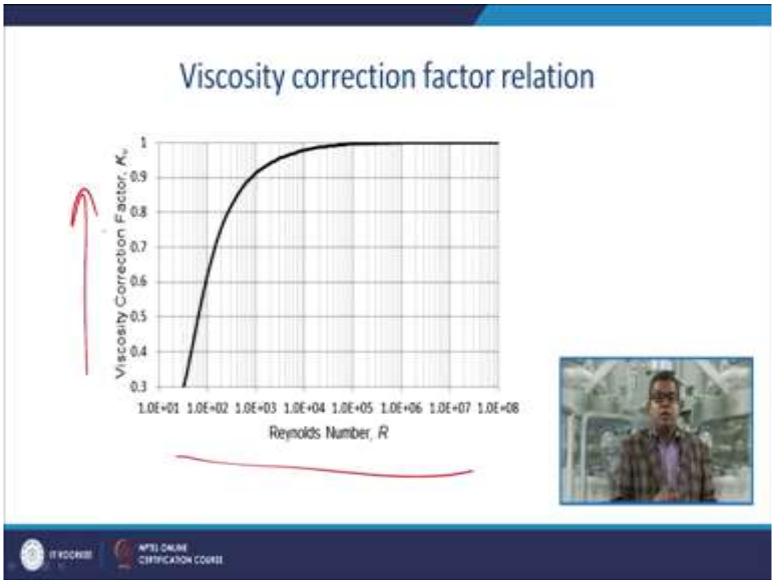
So all in the multiplication factor where K_w is the correction factor for back pressure and Kv is the correction factor for viscosity. So K_v is equal to 1 if your Reynolds number is greater than 16000.

(Refer Slide Time: 18:23)



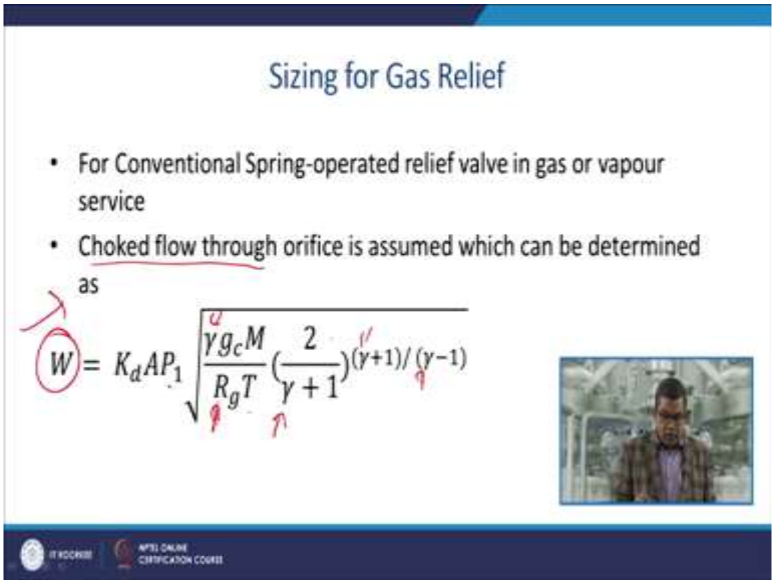
Now this plot shows the back pressure correction factor relation. Now here in the X-axis we are having the back pressure correction factor that is Kw and here the percentage gage back pressure that is Pg in percentage. So you can calculate and you can have a look while you require the back pressure correction factor over this particular equation.

(Refer Slide Time: 18:50)



Now, another is the viscosity correction factor relationship here this particular standard curve is with respect to the Reynolds number and viscosity correction factor Kv, so here in the X-axis we are having the Reynolds number and here it Y-axis we are having the viscosity correction factor. So while calculating the (or if you wish to have the viscosity correction factor K_v) then you can calculate provided that you are having the knowledge of Reynolds number.

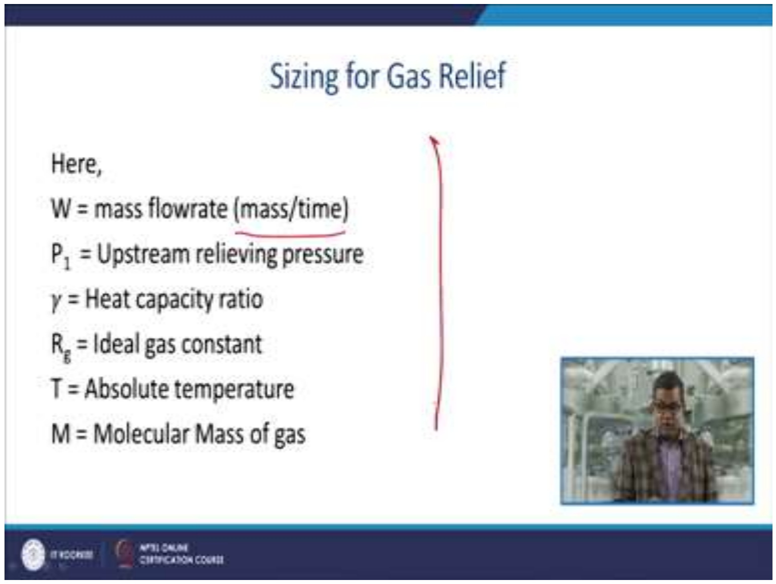
(Refer Slide Time: 19:25)

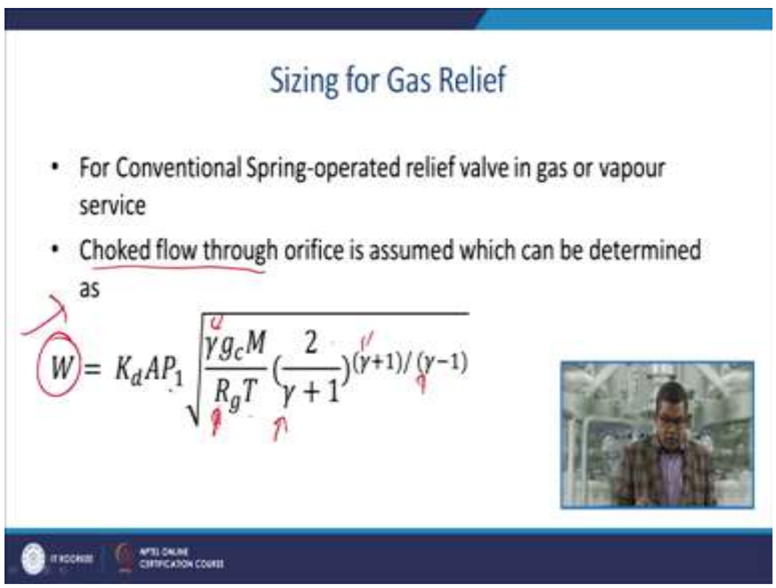


Then we can go for the sizing of for Gas Relief. So this is for the conventional spring-operated relief valve in gas or a vapor service. So choked flow through orifice is assumed which can be determined by this equation. Remember we have already discussed this choked flow in the previous modules. Now, this is defined as

$$W = K_d A P_1 \sqrt{\frac{\gamma g_c M}{R_g T}(\frac{2}{\gamma+1})^{(\gamma+1)/(\gamma-1)}}$$

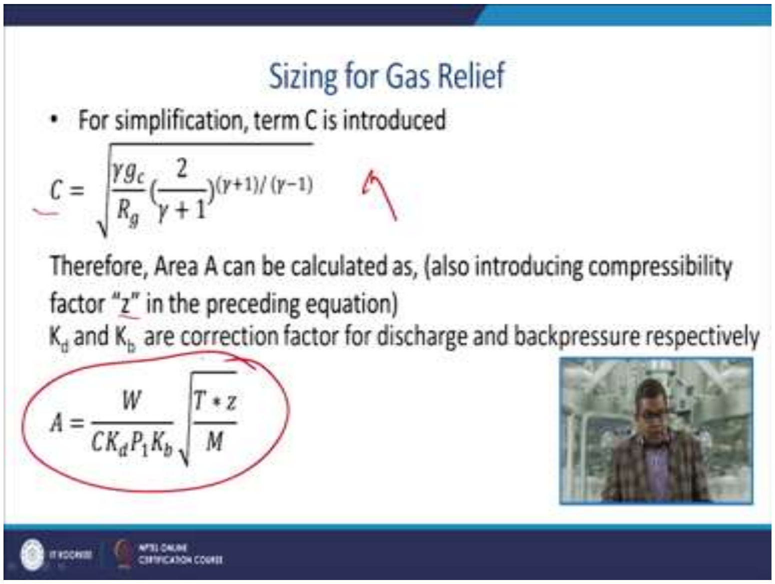
(Refer Slide Time: 20:07)





Now, here W, this W is the mass flow rate having the unit of mass per time. P1, this P1 is the upstream relieving pressure, gamma is the heat capacity ratio, R_g is the ideal gas constant, T is the absolute temperature and M is the molecular mass of gas. So these are the standard denotations of this particular formula.

(Refer Slide Time: 20:36)



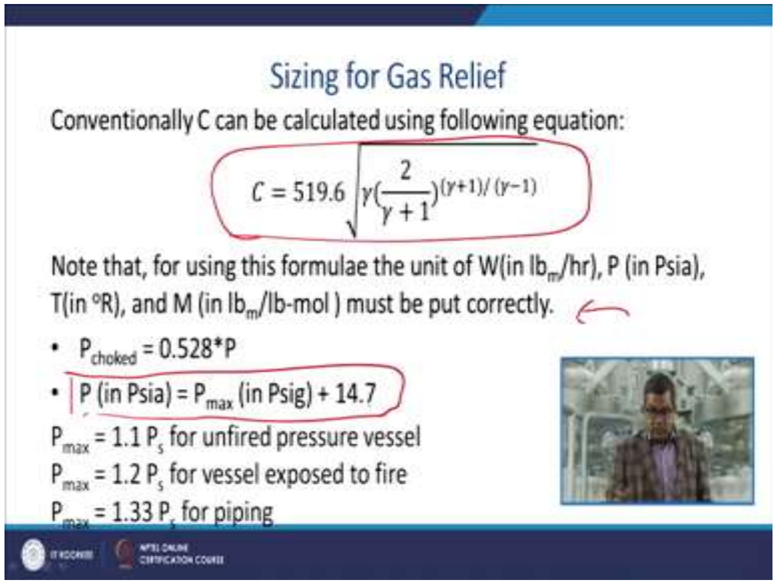
Now, for simplification that we can introduce the term C. Now

$$C = \sqrt{\frac{\gamma g_c}{R_g}(\frac{2}{\gamma+1})^{(\gamma+1)/(\gamma-1)}}$$

So, area A can be calculated as I mean by introducing the compressibility factor Z in the preceding equation which we are using here and Z is the compressibility factor, it is well-known phenomena of chemical in your thermodynamics. So, K_d and K_b are the correction factor for discharge and back pressure respectively. So A can be calculated by this particular equation,

$$A = \frac{W}{CK_dP_1K_b}\sqrt{\frac{T*z}{M}}$$

(Refer Slide Time: 21:26)



So, conventionally we can calculate C by this particular equation by substituting the various values in the previous equation. Now,

$$C = 519.6\sqrt{\gamma(\frac{2}{\gamma+1})^{(\gamma+1)/\,(\gamma-1)}}$$

We have to note that for using this formula, the unit of W is in the ponds upon hour and P in Psia and T is in the Rankine and M is in the pounds per pound mol. They must be put correctly and everywhere while having such calculation the consistency of the unit must be remember.

So P_{choked} is equal to 0.51 (528) x P

and P (in Psia) is equal to Pmax (in Psig) + 14.7,

so this type of consistency must be remembered always. So,

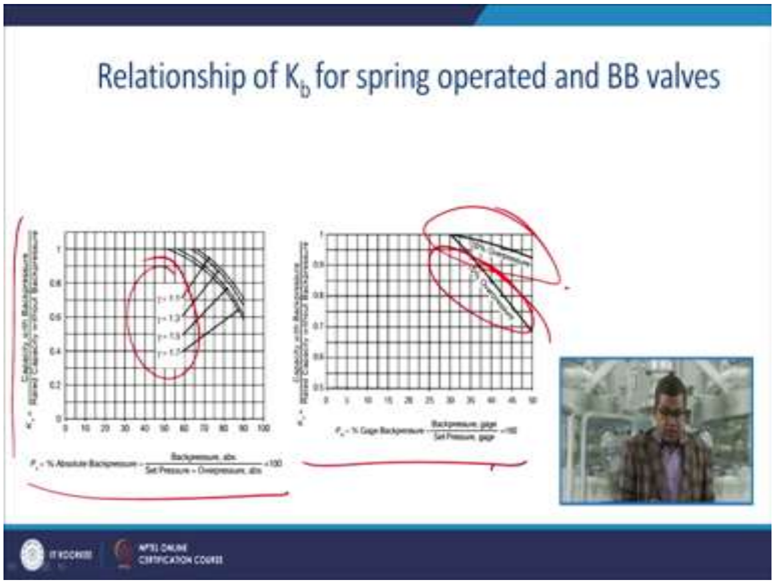
P_{max} = 1.1 P_s for unfired pressure vessel

P_{max} = 1.2 P_s for vessel exposed to fire

P_{max} = 1.33 P_s for piping

So these are the three different scenario.

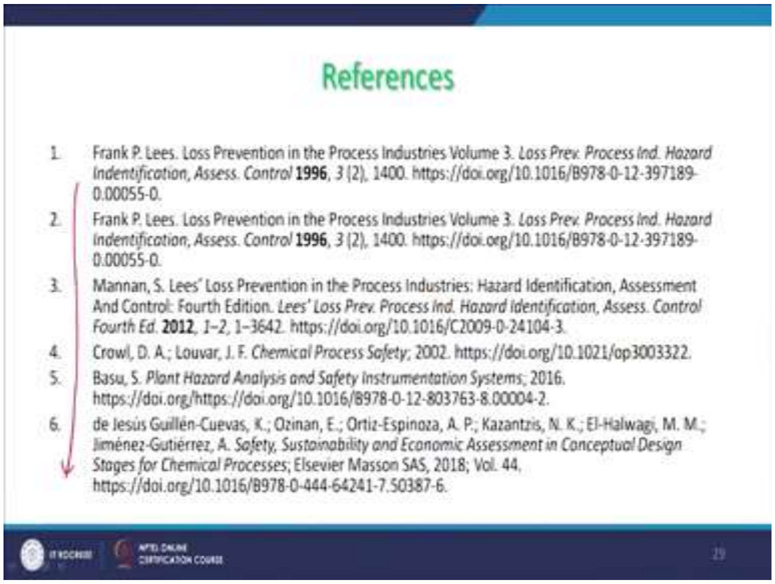
(Refer Slide Time: 22:51)

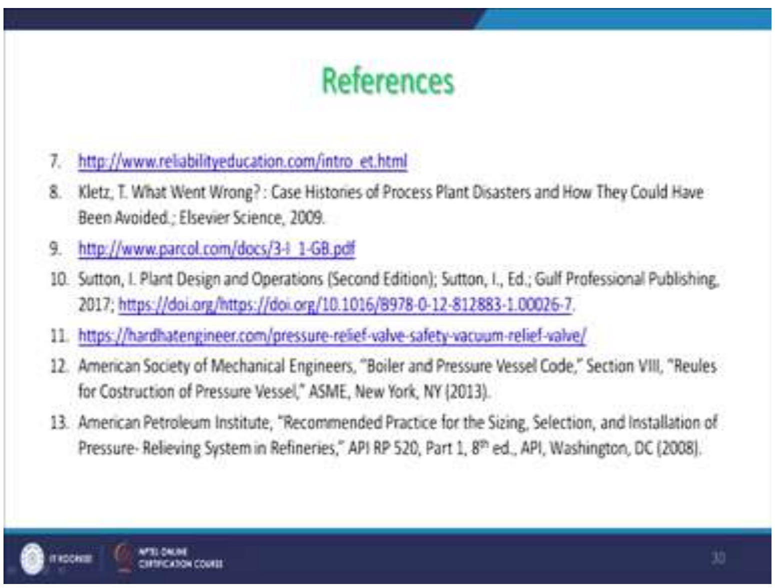


Then we must have a relationship of K_b for spring operated and BB valves. So, here we are having two different plots for the P_b and K_b. Now, P_b is the percentage absolute back pressure is equal to back pressure in absolute divided by set pressure plus overpressure in absolute multiplied by 100 and the K_b is the capacity with the backpressure divided by rated capacity without back pressure. So once you are having this gamma, then you can or you are having the knowledge of this P_b then you can easily calculate the K_b.

Similarly, for this particular aspect when we are considering the overpressure then like 20 percent, 10 percent over pressure, then again, the K_b can be calculated with the help of P_g that is P_g is equal to percentage gauge back pressure equal to gauge back pressure gauge divided by set pressure into 100. So, if you are having these two things you can easily calculate either K_b maybe with respect to over pressure or if you having the knowledge of γ.

(Refer Slide Time: 24:10)





So in this particular aspect, we have discussed the various relief sizing and for the further study, you can always feel free to look into the various references which are enlisted in this particular module. Thank you very much.