Natural Gas Engineering
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Module No # 04
Lecture No # 15
Compressor Design

Hello everyone today’s lecture is on compressor, compressor is a device that is often used in natural gas industry whenever we need a gas to send to higher pressure we have to use a compressor.

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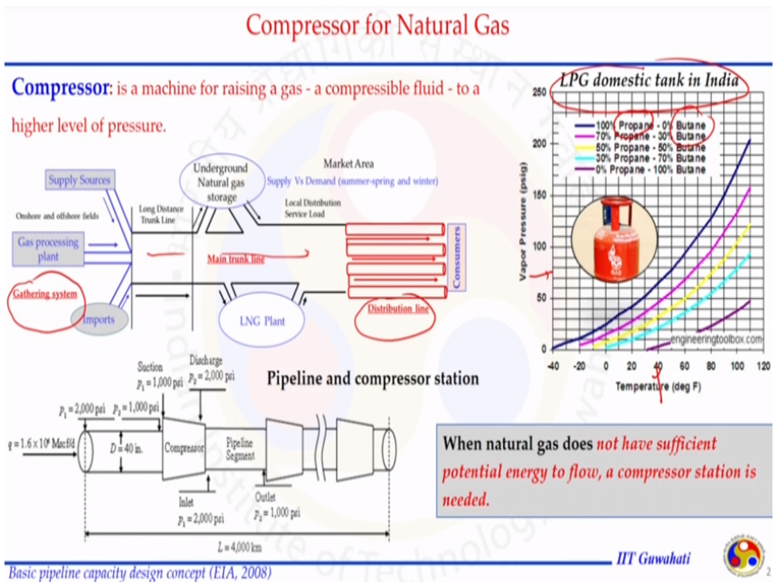

So compressor is a machine for raising a gas or compressible fluid to a higher level of pressure as we can see here when we are transporting natural gas through the pipeline system we are having the gathering system at that place we are collecting the natural gas from several sources including the production wells or the gas processing plants if it is not having enough pressure we need compressor to send it to main line.

Similarly at the distribution end if you want to send this natural gas to a higher pressure we need a compressor. During the main trunk line or the transportation over this long pipe line the natural gas pressure declines because of primarily, because of friction losses offered by the roughness of pipeline that is why at a certain distance compressor station need to be installed at different location to maintain the through put or the rate at which the gas should be transported constant.

And that can be calculated by performing the pipeline design at what particular position the pressure will reach up to certain low level and that low level pressure needs a compressor to compress the gas to send it further. And that calculation depends on pipeline design, layout pipeline at what rate the gas is coming is coming through compression station? And what rate the gas should send back to pipeline again?

Not only during the transportation the natural gas that is in axis need to be stored and for a storage purpose compressor is required and we will see at some other places also compressor is required for example when we are having any unit process let us consider dehydration in dehydration also when we are sending the natural gas to a dehydration unit at a constant rate we need a compressor if pressure needs to be maintained.

Similarly for sweetening and other removal processes another example I had given here is LPG domestic tank in India we can get this LPG propane + butane and depend on the composition of propane and butane filling a bottle or the Cylinder at a particular temperature and the pressure where this will go to liquid phase we need a compressor to maintain that pressure or filling the butane, propane mixture into that bottle.

That is why whenever we need pressure should go up or the natural should be transported stored or injected we need a compressor. During the production also when we are having natural gas is getting produced and because of the liquid loading something the reinjection of natural gas is required or gas recycling is required to send back or to inject the natural gas back in the reservoir formation or in the wellbore we need compressor.

When natural gas does not have sufficient potential energy to flow a compression station is needed that is not necessary in the pipe but at any location from the production to consumer.

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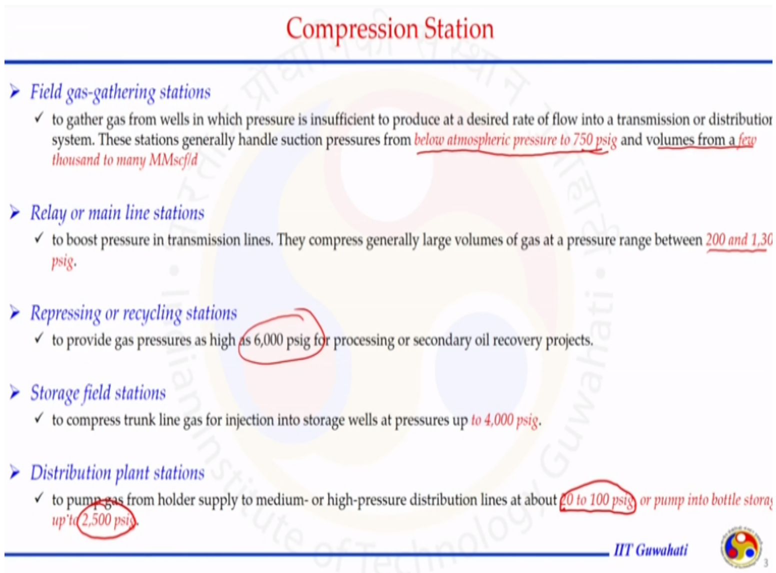

With this background in this class we are going to understand the theory component of the compressor. We will understand the basic theory how compressor does work and the design aspects we are not going to discuss the mechanical design of the compressor like the material of construction the thickness and other aspect it just a theory behind how compressor does work.

So in the discussion of uses of compressor we can see the compressor that con compress the natural gas from one pressure to another higher pressure level depends on the application different types of the compressor design. The primary factor that decide the compressor chose is the quantity of natural gas that should be transported or that should be compressed + the discharge pressure so the pressure at which the gas should be discharged.

So let us see one by one at different application what is the need of this quantity and pressure accordingly the compressor can be chosen. So in gas field gathering system compressor is required to use from below atmospheric pressure to 750 psig. The well which is not producing a compressor can be used as a suction at the inlet condition and discharging at a higher condition and that needs a few 1000 to many mmscf per day capacity of the gas that should be suck from those wells or from particular gathering station to main trunk line.

So main line station they need from 200 to 1300 psig repressing or recycling station they need very high pressure demand like the gas should be compress to 6000 psig for processing secondary oil recovery mechanism as mentioned already the gas may be re-injected in the reservoir formation for enhancing the gas production as well as in the reservoir which is primarily producing the oil.

The gas can be injected and that is comes under the secondary oil recovery mechanism storage field station whenever you want to store either in depilated oil reservoir or in a particular device and that should be stood by high pressure around 4000 psig so significant amount or the volume of the gas can be stored.

Distribution plant station and that is need between 20 to 100 psig range and sometimes as mentioned for the bottling purpose like LPG kind of thing if we are doing this similar thing with the gas natural gas in the form of CNG compress natural gas we are bottling it the pressure should go up to 2500 psig there is a higher horse power compressor is required.

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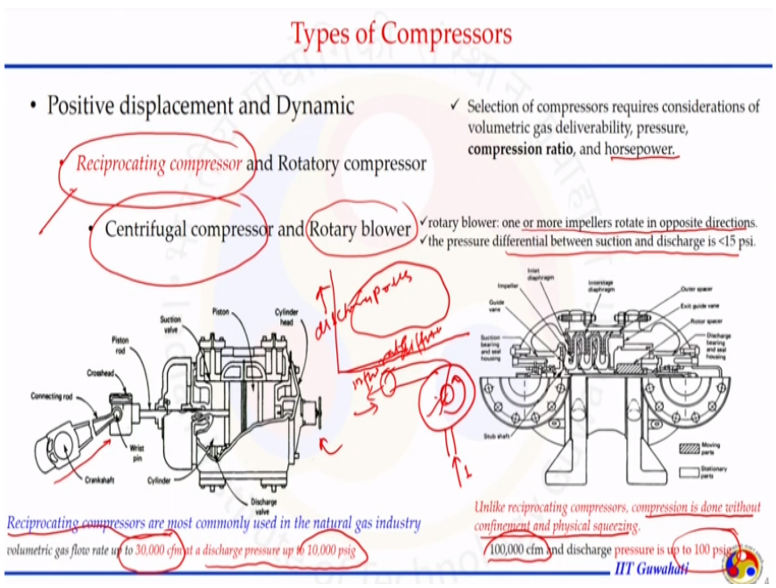

When we come to the type of compressor there are variety of the compressor available in the market and those can also be designed to meet the specific need broad classification is positive displacement is dynamic compressor within this classification the reciprocating compressor and centrifugal compressor are widely used in the natural gas industry and primarily it is reciprocating compressor that is having more application in the natural gas industry.

The selection of compressor required several consideration primarily the amount of natural gas that should be deal with the compressor the pressure compression ratio or it is a ratio of discharge pressure to suction pressure the horse required the cost in involved and easy maintenance and other parameter. For example here we can see this is reciprocating compressor that is mostly used in the natural gas industry it can be used to flow rate up to 30000 CFM and a discharge pressure up to 10000 psig.

So it can accommodate very middle range of the natural gas 30000 but very high pressure 10000 psig. So this is crankshaft that is rotating and this rotation motion is converted to a piston linear motion. So piston and cylinder assembly is there piston is moving inside the cylinder and one stroke it is taking the gas and in the other stroke it is discharging a gas at a higher pressure and that linear motion allow us to increase the pressure of the gas at the discharge end.

Other things about the compressor it has several moving parts that is why the maintenance cost is high compared to centrifugal type of the compressor where the moving part are less and it does not work on the confinement and physical squeezing of the natural gas principle while the reciprocating compressor does work on using the slender that is compress the natural gas and send it to higher compressor.

In this type of the centrifugal compressor here is kind of impeller which is having a rotation and we are getting the gas in at a one location and this discharging at a higher pressure and the kinetic energy getting is converted into pressure energy that is why at the higher end or the diffuser end we are getting gas at a higher pressure this is good for a large quantity of a gas to be handled like 100,000 cfm and the pressure is little low up to 100 psig they are considered very good.

Other categories in rotary blower one or more impeller rotating in opposite direction one impeller is moving in this direction another impeller moving in the anti-clock direction and they discharging gas. The pressure difference between the suction and discharge should be very low up to 15 psig if we need we can go with this rotary blower kind of the device.

This type of the arrangement when we are talking about the choice of a compressor it depends on not only the price but on this chart versus the inflow rate the amount of the gas that should be deal and the discharge pressure. So when we are having discharge pressure on Y axis inflow on the X axis you will see there are several type of the compressor those are falling in this chart they are overleaping also then depend on the other factor like the mechanical losses wear and tear prices availability of the parts maintenance cost we can pick one of the compressor for that purpose.

In this lecture we are going to discuss on reciprocating compressor and centrifugal compressor in detail.

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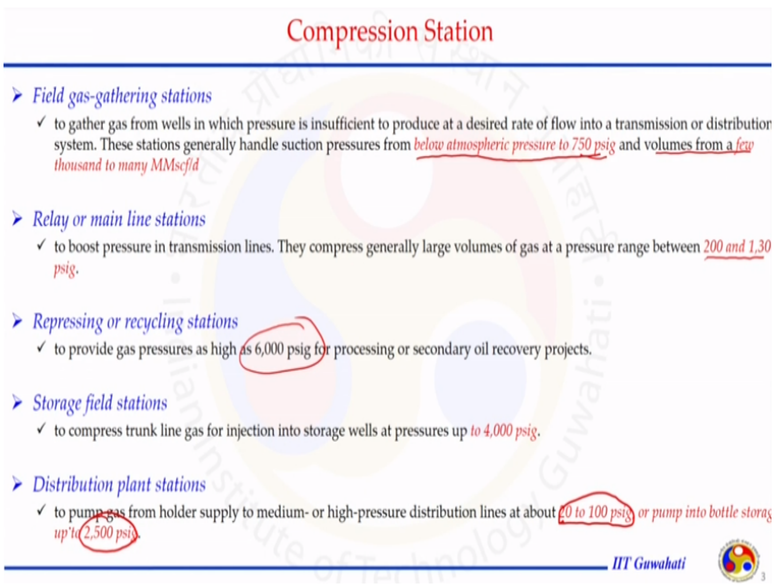

So when it comes for a compressor, compressor are needed to ensure the natural gas gets to the destination this sufficient pressure along the path and outlet that could be path or could be just outlet for a particular segment where the gas needs at a higher pressure. The process depends on as mentioned last slide the overall compression ratio is discharge pressure to inlet pressure means suction pressure we can write this is discharge pressure this is suction pressure.

The ratio is RT it may be written as just R or RT or some other notation the gas capacity is Q that is getting transported the process which design follows this kind of the pV behavior when we are having the pressure on the Y axis and volume on the X axis. So the piston reciprocating compressor where the piston is moving it is going through 4 steps. In first step it is having the part where it is just increasing the volume in the chamber.

And in the second step it is compression and this is step where it is discharging and here shown like this is reaching back to axis but in actual there might be some volume or the clearance volume that remains in the cylinder that should be also be accounted and that should shows like this and the area under this curve is work that should be done by the compressor to compress the gas from P1 low pressure to P2 higher pressure.

The process can be done all this four steps those are happening here the compression and this is expansion this is suction this is discharge. So the process of compression can be done in isothermal manner, adiabatic manner or polytrophic. Most of the compressor to work with the concept of are design with the concept adiabatic compression process but in actually they do work with under the polytrophic condition.

Reciprocating compressor they are more towards the adiabatic compressor while the centrifugal compressor they are more towards the polytrophic mode and move towards the adiabatic if the efficiency can be increased. Isothermal that is if you see here when we are compressing under the isothermal case. Let us consider this part is not there the area under this curve is represented by this we can see the area under the curve when the gas is compressed isothermally is low. Isothermal compression means del T = 0 and adiabatic means del H = 0.

Between both the process this is isentropic adiabatic so this is reversible isentropic process where the energy exchange is not happening under the isothermal condition this temperature is constant. If we can compress the gas under the isothermal condition the less energy is required to compress that gas. But it is not possible always to operate the compressor at a isothermal condition it has to be operate it a very slow motion when the temperature is not changing.

While under the isentropic or adiabatic condition also when we are having this condition the heat flow should not be there but in actual or in practical sense heat happens. Similarly for reciprocating type of the compressor where there should be any clearance volume but within the slender piston assembly during one complete stock some amount of the volume of the gas from the previous cycle remains in the slender and that should be corrected for completing another cycle or the new cycle.

So if compare all these three process isothermal, polytrophic and adiabatic we can say polytrophic which is having this exponent n is equivalent to k when the process is adiabatic and this is equal to 1 when we are having the isothermal process and that is why the polytrophic process can be studied later on it can be converted to adiabatic or isothermal but in case of natural gas knowing the value of n is difficult we can know this k adiabatic or isentropic component by knowing the composition of the gas we understand this from our class on natural gas properties if we know the gamma g we can calculate the value of k.

The area under this curve can also be calculated by performing the integration if we know which path the gas compression step is following it is polytrophic it is isentropic or it is isothermal important point is adiabatic process is mostly followed by reciprocating compressor while the polytrophic process by the centrifugal compressor. So when we are having the expression for 1 form we have to convert into other form when the process is happening in a different manner.

Two other important thing comes when we talk about compressor design how to calculate the power required to compress the gas from P1 to P2 that can be done either by the analytical expression and that analytical expression comes by doing the energy balance across this compressor which is taking the gas at one pressure and discharging at the other pressure or by enthalpy entropy diagram and that also called the Mollier diagram.

And the volumetric efficiency is for the reciprocating compressor where we have to account for this clearance volume also.

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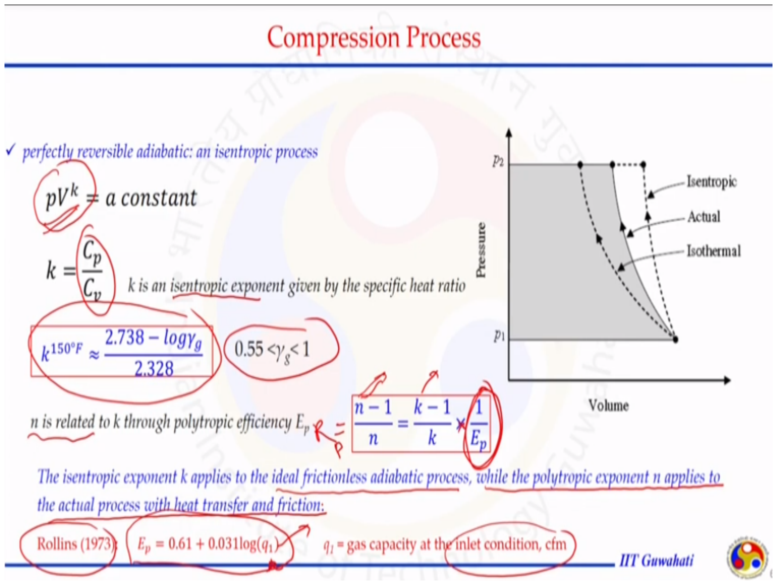

So let us say when the perfectly reversible at adiabatic process is an isentropic process is happening we can say the process is following this path pV to the power k = constant. Again the expression to calculate the area under this curve is done considering the ideal gas behavior and whenever the non-ideal behavior is very much required we have to correct that equation considering the compressibility factor.

Otherwise complexity involve from here itself and becomes difficult to solve the basic equation like pV2 to the power k = constant for isentropic process. If we include the non-ideal behavior or the real gas behavior in it becomes complex. So let us say k is an isentropic exponent it is a ratio of CP / CV at a particular temperature and within this gamma Z versus specific gravity range k can be calculated using this empirical expression.

Once K value is known we are having this pV to the power k we can go through the integral process and calculate the area under this curve when it is polytrophic process the value of n can be related to k through the polytrophic process efficiency Ep and that Ep comes here the relationship is n - 1 upon n that sometime given another expression is R sometime it is RPI. So RP = n – 1 upon n = k – 1 upon k and it is factorize by 1 upon Ep is the polytrophic deficiency.

So if we know the Ep value that will be required on scientifically type of compressor which follows this polytrophic behavior we can calculate the value of n to be use in the isentropic process calculation and Rollins in 1973 given the empirical correlation to calculate the Ep that depends on the amount of the natural gas that is getting compressed so at the suction end or at point 1 he amount of gas q1 means at that temperature and pressure condition the value of q should be known at the inlet condition when calculate the value of n using this expression because we know the value of k.

The isentropic exponent k applies to the ideal frictional less adiabatic process that is already mentioned while the polytrophic exponent n applies to actual process with heat transfer and frictional forces are also getting applied that is why the efficiency should be included to have the conversion from K value to actual value of process that is n.

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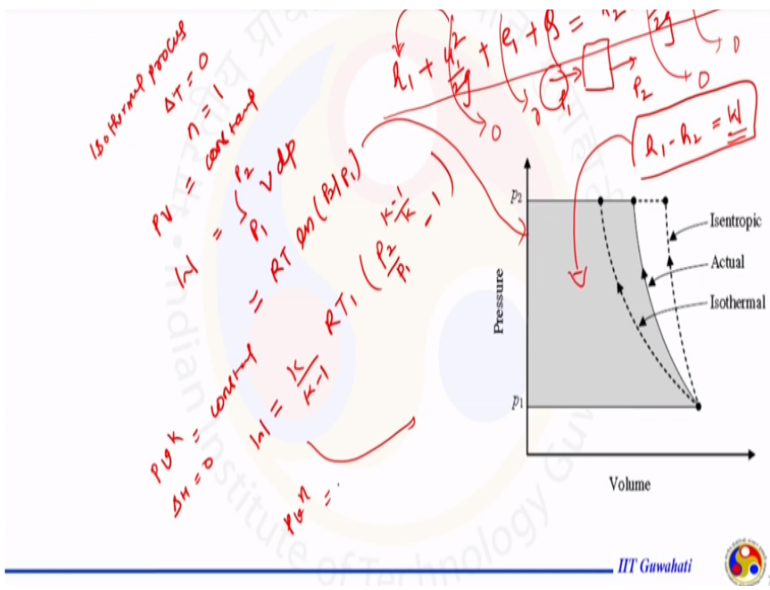

To if we look how this process is happening we can calculate the area under this curve so for example when isothermal process is happening. Under isothermal process del T = 0 as well as n = 1 and we are having this pV = constant and if we do area under this curve that is equal to work done P1 to P2 Vdp and if we do the integral of this converting the or using the ideal gas law we will RT ln P2 / P1.

Now if the process is happening under isothermal condition we can get the work done or work required to compress the natural gas from P1 to P2. Again ideal gas behavior is considered for this case when non ideality to be included we have to modify this equation. In that case most of the time it is not just modification in equation but several empirical formulas are given those account for the non-ideal behavior of the natural gas.

When we are having here the isentropic process we can use this relationship where del H = 0 and we can get the work done w = K upon k – 1 RT1 P2 / P1 to the power k – 1 upon k – 1 again it is for the ideal gas we can modify this thing and this expression is result of mechanical energy balance equation and that mechanical balance equation says to calculate the theoretical work required we have to perform the energy balance.

And that energy balance across the device which is taking the gas at pressure p1 and discharging at pressure p2 should be equal to the enthalpy of gas that is entering to the system that also account the pressure term + kinetic energy if it is as any elevation energy + the Q energy included in the system is equal to at the other hand we are having this H2 + u2 square kinetic energy + potential energy + work done.

We assume in our compressor case considering not only the ideal behavior we also assume there is no change significant in the elevation this should go out. There is no change significant in the elevation this should go out there is no change the kinetic energy or if any change in kinetic energy is happening that can be clubbed with the enthalpy of the system and there is no energy transferred through the system Q is also equal to 0.

And with this balance equation we simply get h1 – h2 = W and this W is work done and that work done is equal to the system which is compressing natural gas p1 to p2 and by integrating of this we can get this W that is equal to enthalpy change of the system to similar for the isothermal condition and isentropic condition as well as for the polytrophic condition we can get the expression for W.

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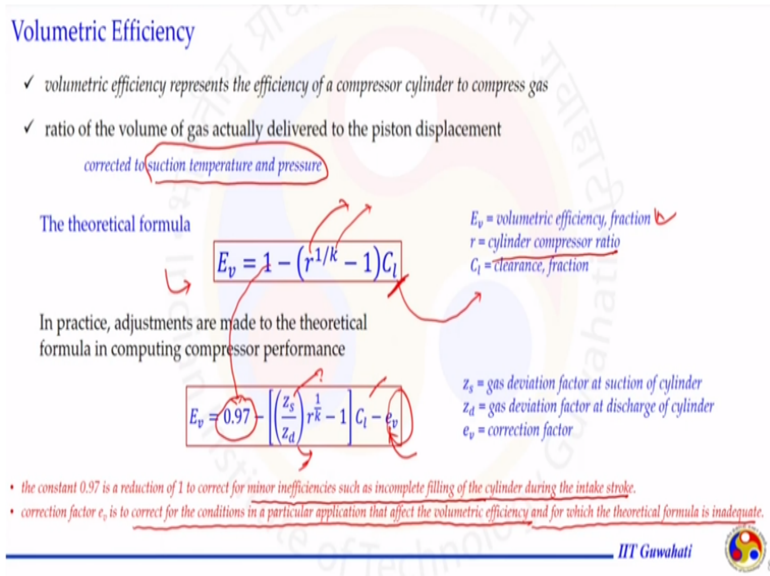

Second part is volumetric efficiency so the volumetric efficiency represent the efficiency of the compressor cylinder to compress the gas as mentioned the clearance volume is still remains in the slender and that should be accounted to consider the volumetric efficiency that is why the ratio of volume of gas actually delivered to the pistol displacement should be counted.

So the ratio of volume of gas actually delivered to the piston and that should be corrected to suction temperature and pressure condition because the gas is a real gas it is compressible behavior or the volume it occupied at a particular temperature and pressure will be different. So we have to correct the volume of the natural gas at the inlet temperature and pressure condition to account for the clearance volume.

And instead of calculating the volume it can be done by applying the theoretical formula for volumetric efficiency where R is cylinder compression ratio where discharge pressure to suction pressure Ev is volumetric efficiency that has no unit and Cl is the clearance, k is having this isentropic exponent in the system. In practical adjustment are made to theoretical formula in computing compressor performance.

Again this is considered for the ideal gas where clearance volume or fraction of volume that remains in the cylinder is accounted to calculate the Ev while in practical sense this 1 is not 1 that may be deviation and that should be accounted as 0.97 to correct for minor inefficiency such as incomplete fitting of the cylinder during the intake stroke. This Zs and Zd are compressibility of the natural gas at suction end and at discharge end.

And Cl is same clearance volume another term Ev is included that is also correction factor that is to correct for the condition in a particular application that affect the volumetric efficiency and for which the theoretical formula is inadequate formula so the value for the volumetric efficiency is not considering the local conditions at which this efficiency should be calculated and for that purpose this is small Ev should also be included in the expression to account for such kind of the corrections.

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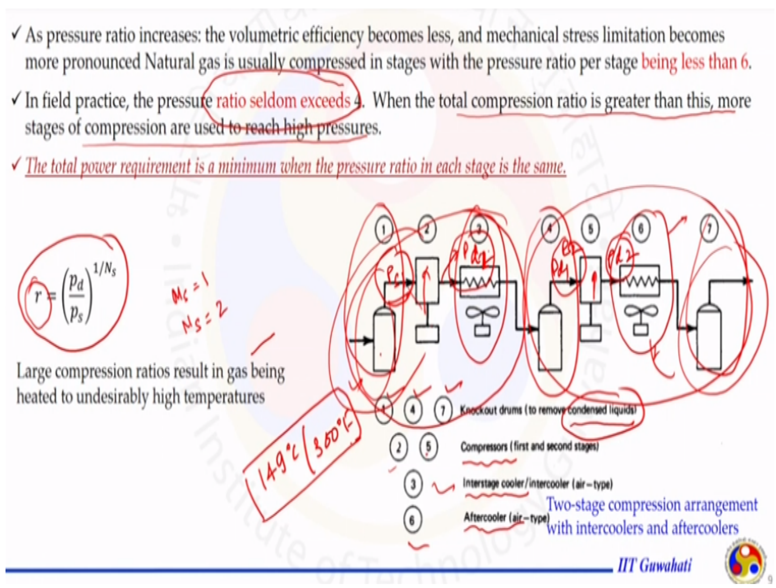

So far we understood like gas can be compress from 1 pressure to another pressure we can calculate the area under the curve and can calculate the work required to perform that compression process. But the discharge pressure is sometimes is too high compared to suction pressure it means the compression ratio is very high and in that case the heat release during this process significant is high.

And because of that the energy required or work done should be more because we understand from our graph or Pv diagram the work done under the isothermal condition is the lowest one. So the objective should be we are compressing our natural gas in that or near by the isothermal condition. As it is deviating from isothermal condition going towards the isentropic condition more work is required that is why the temperature the temperature change happening during this compression process when we are compressing the natural to a very high pressure the more temperature increase will be there.

Not only the energy required will be high but the damage to the compressor the ceiling fitting those are not appropriate to handle that temperature will also get affected and in that case it is a good idea to perform the compression in this stage to avoid the losses or damage to the compressor as well as the energy required to compress the natural gas from P1 to P2 the cost will increase when we are having the multiple compressor but that can be compensated by reducing the maintenance cost.

So in field practice the pressure should not exceed 4 so when we are discharging the gas from P1 to P2 should not be more than 4 times of P1 and if it is happening the system should be divided into number of stages and the total number of stages depends on the suction pressure to final discharge pressure. When the total compression ratio is greater than 4 more number of stages are required to reach the final pressure the total power requirement is a minimum when the pressure ratio in each stage is the same.

So the compression ratio should be defined in such a manner that in each stage the compression ratio is same. So from stage 1 for example here we are having the two stages this is altogether is one stage and this is second stage so in each stage for example stage 1 the compression ratio like the discharge for example here this is a discharge so I should say Pd to this is Pd1 from discharge this is Ps1.

So gas is going to compressor at Ps1 getting discharge as Pd1 again this pressure will be Pd1 as a Ps2 for the second compressor and the discharge will be Pd2. So the ratio of this to this for compressor to should be same as the ratio for compressor 1 this Pd1 divided by Ps1 and in that case the energy required to compress the natural gas will be less. Number of stages required can be calculated using this formula that says R over all compression ratio or the compression ratio for each stage is equal to Pd / Ps 1 upon Ns.

And if we are having only one stage then Ns = 1 if we are having 2 stages Ns will be 2 and similarly we can add on the things. When we do the stage wise compression some other unit are also associate and that include like here in diagram 147 so you can say this 1, 4 and 7 these are the knock out drums and they are that to remove condensate liquid thus significant amount of the liquid is still present in the system and this should not go to compressor they should be taken out some small particle or something that is happening in the compressor or during this process where the small particle from the metals are also coming to the fluid should also be removed with the help of this knock out drum.

And then it goes to compressor and we know when it is going to a compressor gas will be compressed temperature will be increased under isothermal condition will required the less energy and that is why the intercooler are installed between the two compression stages to maintain the temperature as an so the gas going to stage 2 is having the same temperature as going to 1 with the help of intercooler this can be after each process.

This intercooler is also even after completing the compression process 1 and 2 when it is going to this pipeline. So 2 and 5 are compressors these are compressor 1, 2 compressor are there with the tag name of 2 and 5, 3 is inter stage cooler and 6 is after cooler that is here. So the large compression ratio result in gas being heated to undesirably high temperature that is why we perform the compression in this stage manner.

And when we are having this stage manner as already mentioned the smaller compression ratio is preferable to have the isothermal kind of the situation and the discharge temperature should be below 149 degree C or 300 degree F to have no damage to the compressor.

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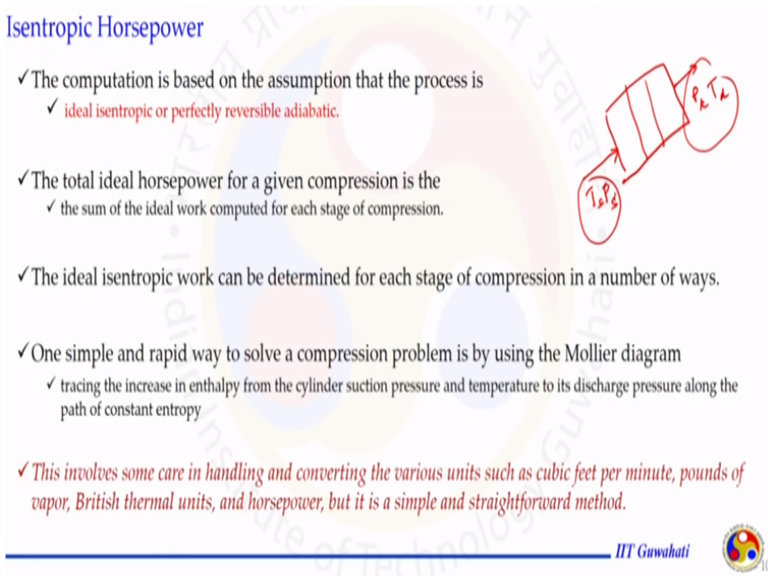

The computational is based on assumption that the process is ideal isentropic or perfectly reversible adiabatic process that we had performed but in field this is not going to be the total ideal horse power for a given compression is the some of ideal work computed for each stage of compression. So when we are having the multi stage compression station the total power compressing 1 using just 1 compressor and having multiple compression should be compare while we are adding compression power required for each stage in the stage compression process.

There are several ways to calculate the isentropic work we have discuss one way is analytical expression that can be obtained by performing the integral of the curve on the Pv diagram. Second we will discuss soon that is the Mollier diagram and in the Mollier diagram it is a rapid way to solve a compression problem and just need to trace the increase in enthalpy from the slender suction pressure and temperature to discharge pressure along the path of constant entropy.

So we are assuming it is a isentropic process it means for example we are having a device where the temperature and pressure at the suction head are given. Similarly on the discharge head this is Pd this is Td and if intermediate stages are happening for either single stage or multiple stage the constant entropy path line should be followed and the difference in the enthalpy from this condition to this condition should be read from the Mollier diagram.

This involves some care in handling and converting the barrier units such as cubic feet per minute pounds of vapor BTU horsepower and it is a simple and straight forward method. So when we are reading the Mollier diagram we have to be careful the way it is reported or given.

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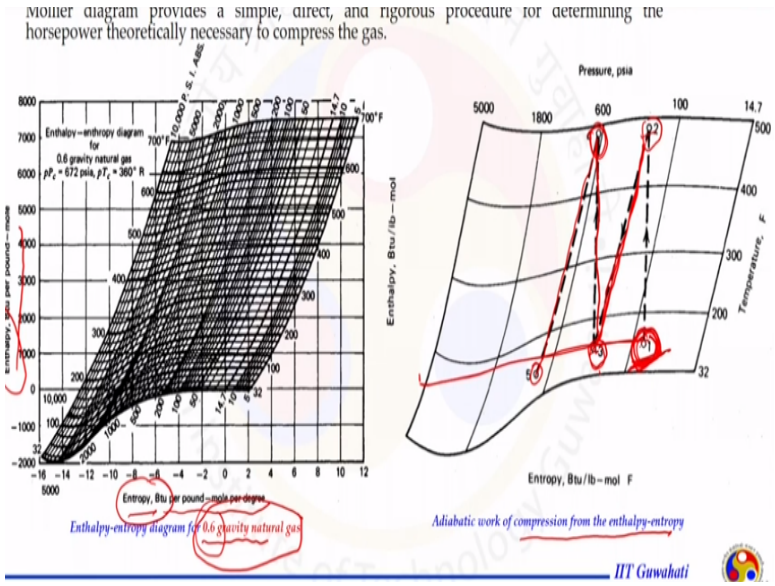

So if we see here the X axis is having the entropy and Y axis I having the enthalpy and we can see here the entropy unit is given BTU per pound mole and per degree and the enthalpy unit is given as BTU pound mole and those are little different then the value we are counting. So we have to be very careful converting the unit to read this chart and after reading this chart we are going to report or convert the value in the desired form we want to work done to compress this much amount of the gas and that could be in scf, mmscf based on the mass based on the mole we will see that.

So the Mollier diagram provides a simple direct and regress processor for determining the horse power theoretically necessary to compress the gas. Again it is a theoretically not including any efficiency determine because we are considering it is perfectly adiabatic isentropic process and under that condition we can read that chart. For example we are having the gas it is compositions are known it means we know the gamma g the specific gravity.

Because the Mollier diagram are different for different gravity natural gas this chart is shown for 0.6 gravity natural gas. If we are having 0.7, 0.8 even intermediate 0.65, 0.75 the chart shape or the location of the lines appearing in this chart will be little difference. So let us read this chart where we are at point 1 the initial suction head and if we are having the number of stages for the compression.

For example we are going from 1 to 2 we have to go straight up and then follow the constant entropy line till the point we are reaching 3 and because of the cooler inter cooler arrange the temperature is same as 1 we are reaching at point 3 and from point 3 we can go to again another compression stage we are reaching at point 4 and when we are cooling it down we are reaching at point 5.

During this entire process when we are compressing from for example from 1 to 2 we can see on the Y axis we can read the change in the enthalpy of the system that is happening well compressing the gas from one point to another point. So thus with the help of the Mollier diagram having the entropy enthalpy relationship in the form of a chart we can calculate the enthalpy change happening in the process that could be either the single stage process or multi stage process.

Important is this is for the adiabatic work of compression and for the real gas this is accounting in terms of different chart. Different chart in the sense this for 0.6 and similar chart can be get for the other gas composition means the behavior or the composition of the gases are accounted in terms of the gamma g.

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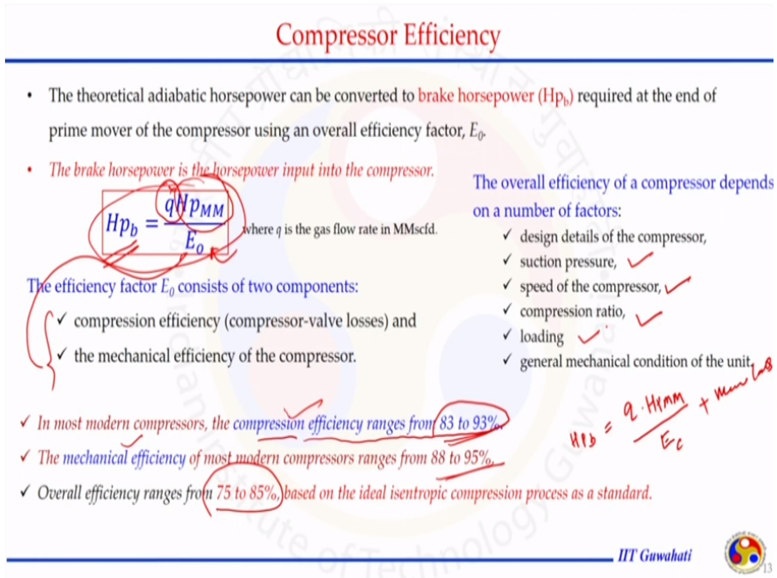

Another approach that we already discuss the area under the curve will give us the mathematical equation that can be used to calculate the horse power for each stage and again it is for the isentropic work formula we can use this similar expression for the isothermal case and polytrophic case also.

The numerical factor will appear when we adjust the unit associate with each parameter and we got the expression that will allow us to calculate the work or the power required to compress the gas which is having K value is this isentropic exponent as K gamma g is the specific gravity from p1 to p2 pressure and when this equation is used we have to consider the unit associate with it. For example here now the work is measured in fit per lbf per lbm at other like temperature and degree ranking gamma g is ok pressures are in psia but this unit is different in this expression if we change this unit to other form you will different volume of the numerical constant here.

When the deviation from ideal gas behavior is applicable it means the pressure we are dealing with if the compressibility factor is going to a play a major role in calculating the tableau the work or the power required we have to include that in the expression and that can be done just by putting Z1 means compressibility factor value at suction end in the expression the similar expression is here and that represent the real gas behavior.

But we see there are several empirical behavior formula available in the literature and they account both Z1 alone is suction head compressibility and sometime both suction head compressibility and discharge compressibility in a more complex form if we write this expression in terms of power we are going to get this is just a representation of this considering some base temperature and pressure consideration we will get numerical coefficient here constant value of Pb and Tv in the expression.

Again this is having similar expressions Z1 is appearing here along more complex expression more empirical formula will give us both Z1 and Z2 in the expression. So we can calculate the power required to compress the natural gas required the natural gas under isentropic condition to pressure P1 to P2 and it depends only on the T1 suction temperature not at the discharge temperature because the compression process will generate the temperature and the discharge and will have a different temperature depend on the type of the compression has been chosen as well as the pressure ratio P2 to P1.

So the theoretical adiabatic horse power can be converted to break horse power that is required because the break horse power is the horse power input into the compression. So whatever we assume 100% efficiency of the compressor is going to compress the natural gas while considering this area under this curve or just performing the numerical integration over the expression we got by the energy balance equation.

But the break horse power is something that is actual value of the power going to compressor and that can be calculated like q the amount of natural gas that is going to be compressed multiply by the HpMM. If we go back and we see here the HpMM is required theoretical compression power per mmscfd so we have to multiply this with q value to have the energy unit and divided by the efficiency of the system that Eo. Eo represent for both type of the efficiency those are associate with the compressor like the compression efficiency and the mechanical efficiency of the compressor.

So the compression efficiency means as we discuss in the displacement type of the system where the clearance volume remains there that should be included in the expression and the mechanical efficiency means the mechanical losses those are happening when the piston is moving inside the slender the mechanical losses will be there and those should be accounted. So the mechanical efficiency account for mechanical losses that happens during this compression process.

Sometimes we can divide this into parts where we are having this break horse power Hpb= q HpMM divided only the efficiency or compression efficiency of the compressor that we can say ~~e~~Ec+ mechanical losses in a separate term. But it is a good idea to combine both of them together represent by E0 that accounts for both the factors in most modern compressor the compression efficiency ranges from 83 to 93% that already mentioned the friction happens there the efficiency is not 100% as we consider the frictionless process and the compression efficiency various from 83 to 93%.

The mechanical efficiency various from 88 to 95% and if we talk about the overall efficiency of the system because of this not 100% compression efficiency and not 100% mechanical efficiency the overall efficiency comes in the range of 75 to 85% only because we consider this as ideal isentropic compression process.

So the overall efficiency of a compression depends on number of factor that we can count suction pressure speed of the compressor, compression ratio this we discharge pressure the amount should be compressed and some general mechanical condition of the unit that which type of unit we are going to use. How many moving parts are there in that particular type of the compressor.

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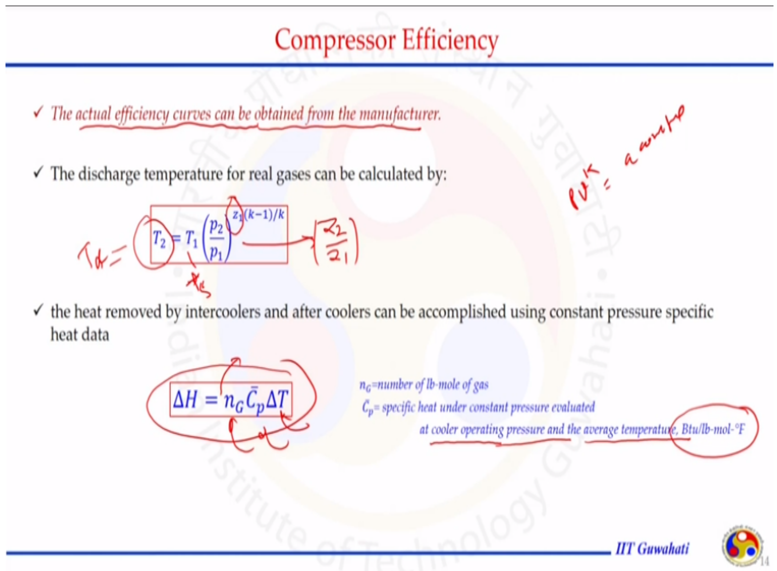

The actual efficiency curve can be obtained from the manufacture so those manufacture those are supplying the compressors to us we can go and ask for a efficiency curve and that efficiency curve account for the factor those are responsible for calculating the mechanical efficiency as well as compression efficiency because both also depend on the pressure ratio we are using as we had seen in volumetric efficiency expression that accounts for p2 / p1.

So the overall efficiency is a function of compression ratio as well as the amount that is going to be delivered that is a chart should be provided the manufacture when we go to vendor and ask also ask us certain things. So we should be very known some of the things those we have to tell to a vendor.

For example the site elevation where we are going to install this compression what is the elevation at that site inlet pressure outlet pressure discharge rate and the gas that is going to be handled by this compressor gamma g, Cp specific heat at constant pressure the value of k isentropic exponent and compressibility factor and are included in our mathematical expression that is where both value should be known.

Another way is just using the Mollier diagram that does not need all these calculation but again that is for the ideal condition isentropic condition and for the polytrophic condition we have to adjust considering the gas composition also. So the discharge temperature for real gas can be calculated we know we can do again this Pv to the power K is a constant we can do this at one condition and another condition we can get this discharge temperature t2 this sometimes written as Td also = Ts that is the suction temperature.

P2/P1 the compressibility is added here to account for the non-ideal behavior and sometimes we will more complex or more accurate expression where z2 / z1 is multiply with this function to have the discharge temperature value. So when we having the value of T2 known the discharge temperature from a compressor and when we are going to apply the inter cooler or the after cooler if it is just the single test process we can calculate the amount of the heat that is going to be removed and that can be calculated del H = nG number of lb moles of gas.

Cp is the average specific heat under constant pressure evaluated at cooler operating pressure and the average temperature the unit is written here otherwise numerical coefficient will come here and delta T is the temperature difference that we are going to achieve with the help of a intercooler or after cooler.

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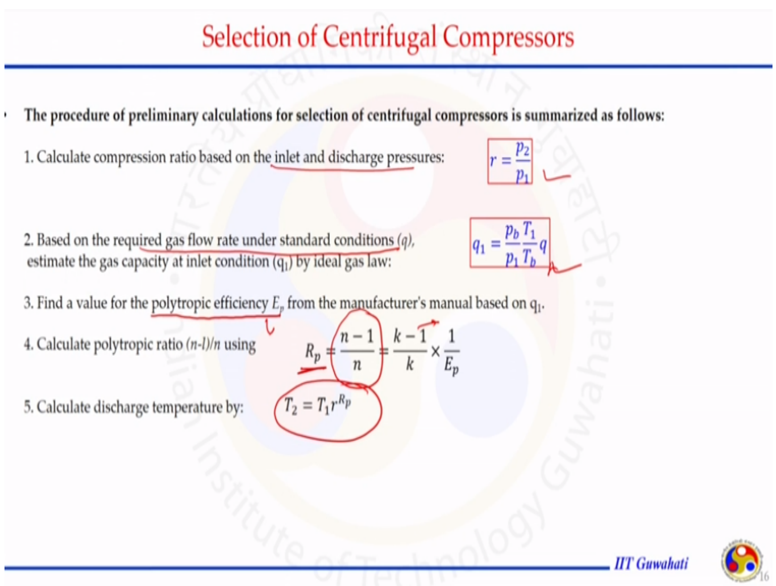

We can go through one example that will give us little bit more understanding about how these calculations are done. So for example we are having a gas that is having specific gravity gamma g = 0.8 and that is compressed with the help of a compressors this is our compressor at the suction end we are having 80d degree Fahrenheit temperature and 100 psi pressure.

This is compressed to 1600psia let us say the specific gravity is 0.6 we can take the some example as given in the book. So we are having this temperature and pressure condition at the suction end and discharge end we know the pressure we can calculate the temperature the expression we just seen let us not worry about that the we have to consider how many stages we should use.

So when we calculate the compression ratio that is says the discharge pressure divided by suction pressure and this is coming out as 60 and this is more than 6 more than 4 also that is why we have to go to number of stages and that number of stages if we take 2 so then again 1600 divided by 100 to the power 1 / 2 we are going to get 4. So the pressure ratio is less than 6 when we are having two stages process and in each stage process the pressure is going to be four times.

So one process or in one stage we are having 100 is going to 400 psi and this 400 is going to converted into 1600 psi and as we understand there will be a need of cooler to maintain the temperature that we can calculate because we know the temperature here by using the expression we can calculate the temperature going to be here or we can install the intercooler that is going to convert this temperature back to the inlet temperature of 1 and that again another intercooler can be or after cooler can be here which is going to bring the temperature again 80 degree F.

So in that manner we are going to get the same temperature at the end but the gas is compressed from 100 to 1600 psia you can perform this calculation and putting everything in this expression we can calculate to do this thing how much horse power required. And as we are having the two stage process.

We have to do this two times one for the first stage another for the single stage and if we do that thing in the first stage we are going to get HpMM = 73.3 because we know this K value because we know the gamma g we calculate the K value this value is known temperature pressure at P1, P2 known to us Z1 compressibility can be calculated by using the brill and backs method K is further known we can calculate HpMM.

But in second case this P1 will become 400 and p2 will become 1600 so in second case we are going to get HpMM 2 is little different this is 69.5hp per mmscft similar here this is Hp per mmscfd. Now the total compression power or theoretical power required is summation of both that is comes out as 142.8. Now we can do further calculation and calculate the break horse power if we understand how much gas is getting transported or compress using this compressor the Q value and if we know the efficiency of this compressor.

If both are given we can calculate the temperature we can do the intermediate cooling process also and similar we can do with the help of the Mollier diagram also for the scientifically compressor the processor could be more or less similar little bit different we can say first we have to compressor ratio based on the inlet and discharge pressure this is okay if multiple stage is required again we have to go through this multistage compression process concept.

Based on the required gas flow rate under standard condition we can calculate the gas that is going to be compressed at the inlet condition we can use this relationship and the value of polytrophic efficiency Ep can be calculated as shown in previous slide using the Rolle's formula and once we know the Ep we know the K value we can calculate this n – 1 upon n it is also known as Rp we can calculate this value of Rp using the Rp value we can calculate the temperature T2 at the discharge end.

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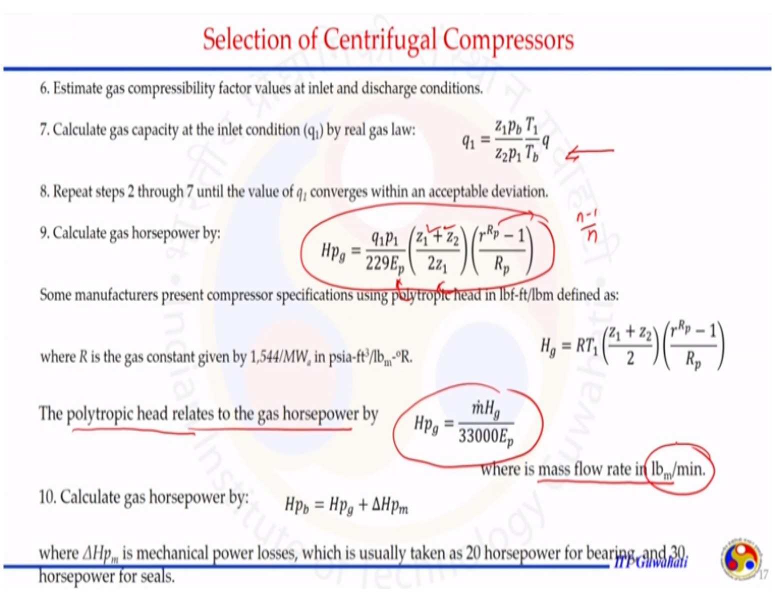

And in next calculation we can estimate the gas compressibility factor values at both inlet and outlet condition because we know now the discharge temperature also calculate gas capacity at the inlet condition considering the real gas law. Now we had included gas compressibility at suction end at the discharge end in the expression and let us repeat this processor from step 2 again until the value of q1 converse with this acceptable deviation.

So in the previous time we just had converted this q1 using the value of q given to us perform this calculation considering a particular efficiency of the compressor and we go this q1 value again in the step 7 and we have to perform the calculation repeatedly till the satisfactory answer is achieved. Calculate horse power little bit more complex formula because the way compressibility is accounted.

So it is average of compressibility z1 + z2 / 2z1 so the average of z1 + z2 / z1 is included there Ep the polytrophic efficiency of the process and Rp that equal to -1 upon n and similar manner can calculate some other parameters like the polytrophic head related to gas horse power can also be calculated where the unit is in mass flow rate in lbm per minute.

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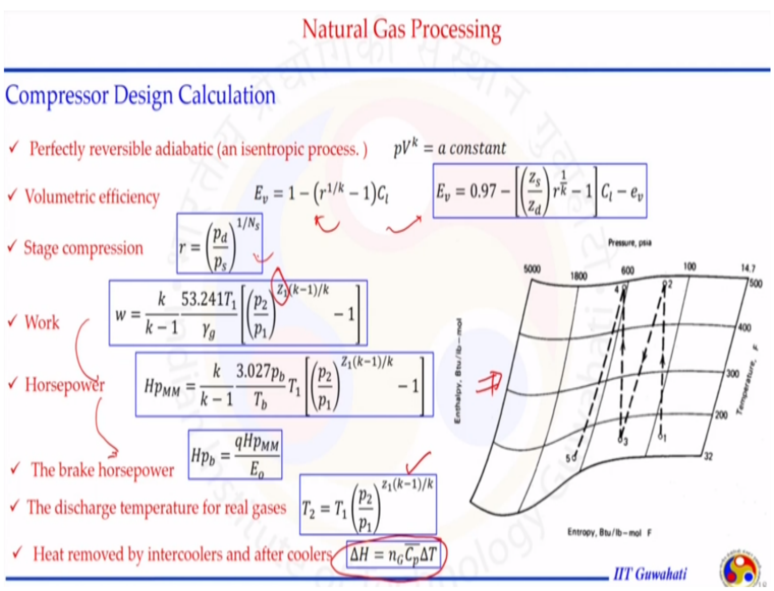

The efficiency of the scientifically compressor should be included calculate the value of n that is polytrophic exponent and other for calculation should be performed to have the work or the energy or the horse power required to compress the natural gas from P1 to P2 the expression may be different in terms of how the compressibility is included in the real expression. So let us summarize the compressor design calculation that is where we consider perfectly reversible adiabatic process Pv to the power k is constant.

We could also consider the volumetric efficiency using this expression more complex expression could be there accounting for the real gas behavior. The stage compression is a concept where the gas can be compressed in a stage wise manner and in that stage wise manner we have to calculate the number of stages required once we know that thing the work done in each stage can be calculated considering the area under the curve and the Z1 can be included here account for the non-ideal behavior more complex formula can also for the possible considering the accuracy of the work is required.

Horse power work can be converted into horse power required to compress the natural gas and the horse power to calculate the break horse power because this theoretical horse power it does not include the efficiency of the compressor the discharge temperature by using the calculation buy using this expression and the heat removed by intercooler is just by this expression similar thing can be done at least upto this enthalpy or the energy required during this compression stage with the help of Mollier diagram that represent enthalpy versus entropy relationship for a specific gas that is having particular gamma g.

By changing the gamma g the chart will get changed with this I could like to end my compressor class that had given us the idea of how to design some part of the compressor when we are going to purchase a compressor we have to have the understanding of some of the basic things those needed to choose a particular time and size of the compressor with this I would like to end my today’s lecture we will meet in the next lecture so thank you.