Natural Gas Engineering
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Module No # 04
Lecture No # 18
Transportation of Natural Gas – II

Hello everyone so today's lecture is a continuation of previous lecture on transportation of natural gas. So let us recap quickly what we had gone through in the last lecture on transportation of natural gas.

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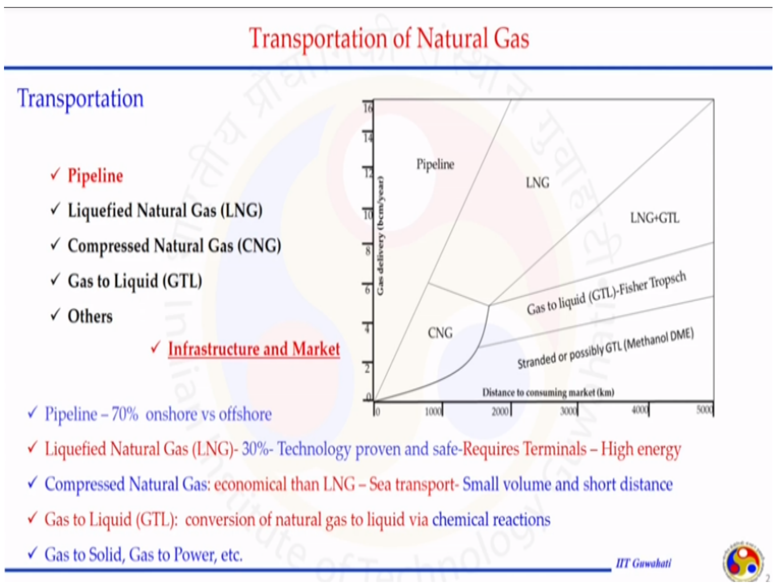

So when the natural gas is purified it is ready to go to consumer in different form like the natural the gas can be transported through this pipeline in the form of LNG, CNG, GTL and others. We discussed based on the amount of the natural gas to be transported and the distance or terrain it covers the appropriate mode of transportation can be chosen we discuss in detail about the pipeline briefly on the LNG, CNG and GTL the infrastructure and market available for the natural gas is also one of the major factor that determines which mode of the transportation of natural gas should be chosen.

If there is adequate infrastructure or LNG or CNG mode and the demand at the user side is significant at a local place or at a distance place appropriate mode can be chosen.

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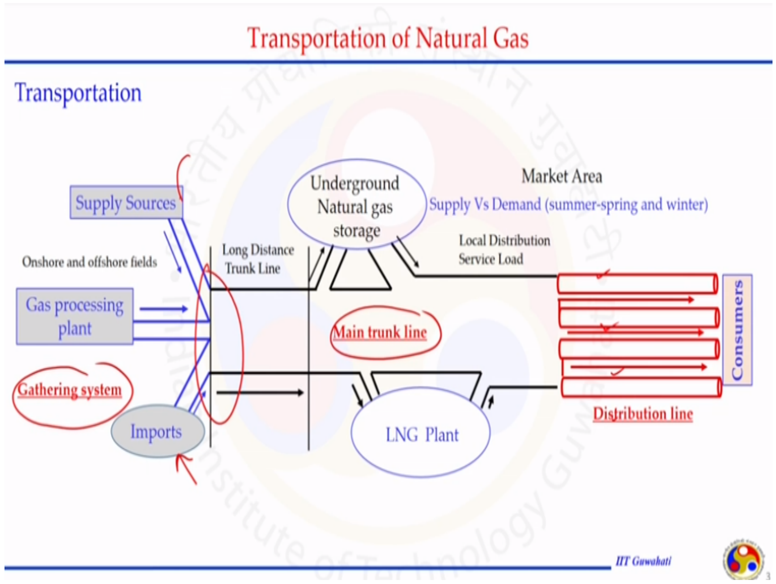

In the last lecture we focus on transportation by pipeline where we understood the pipeline system can be classified in three ways gathering system where the natural gas from different sources is gathering this is from different wells different gas processing unit that is why this part should be chosen at a appropriate place where it is able to cover large number of the gas well in the same reservoir pool.

Now this should also have the facilities to accommodate the gas that is imported from other place or some other sources. Then it travels through this main trunk line the big diameter pipeline reached to a place from where it is distributed again through a small diameter pipeline to consumer.

Consumer can be individual houses in that case or others in between these two the gathering station and consumer it is not only the pipeline that is playing a major role for transporting this thing other factors associate with transportation of natural gas like the supply and demand that should also be considered for that the storage facilities either in the depleted well reservoir or in the LNG form.

IN LNG plant facilities should also be designed as a part of pipeline design system there are significant number to pressure to maintain the pressure or to maintain the through port of the natural gas from one place to another place should also be considered.

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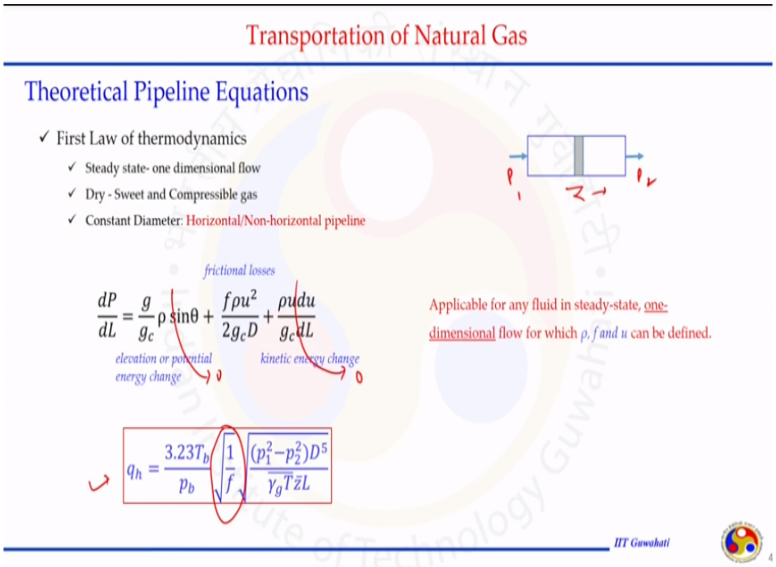

And to do that in the last lecture we started setting up the mathematical equation using the first law of thermo dynamics so for a case of steady state one dimensional flow in the Z direction from pressure P1 to P2 we could setup the mathematical equation and that says the pressure drop in this pipeline is because of gravity friction and kinetic plus there might be shaft work some other part.

Certain terms can be dropped we did for the case when the pipeline is horizontal this is not contributing constant area constant diameter pipeline. So the kinetic energy is also not contributing and the simplification of this equation after considering how to calculate F rho and u we could establish the relationship that says how the desired relationship that is Q is a function of pressure difference like P1 and P2 both the terms are appearing the expression along with dimension of the pipe and fluid properties.

So this is the standard equation depending on how we are substituting for this root of 1 by F this is the transmission factor we can get different form of the equation.

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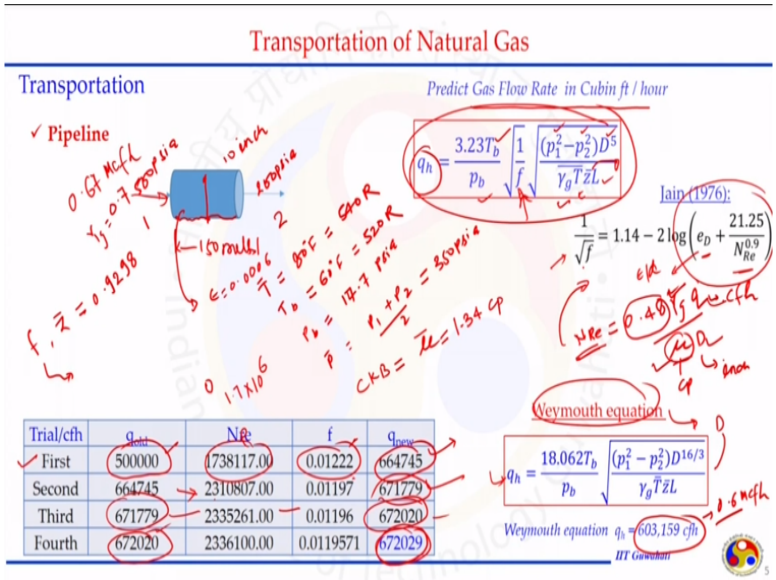

And considering that we could set up the equation like a Weymouth equation Panhandle equation Panhandle B equation. So with this back ground of the last lecture let us solve a problem where it is a given a pipeline is designed to transport the natural gas from point 1 to point 2. The conditions are given like the diameter of this pipeline is 10 inches and the length is 150 miles.

The pressure at 1 end the P1 point is 500 psia and it is delivering the natural gas to other point and the point where we are understanding the performance of this pipeline the pressure at point 2 is 200 psia so tube of 10 inches diameter 150 miles long is transporting natural gas at one end it is 500 psia another end it is having 200 psia we can consider as the equation arrived in the last class considering no kinetic energy no shaft work is being applied on the system the constant diameter pipeline as well as under isothermal conditions.

We can say the average temperature is also specified and that is given is 80 degree Fahrenheit that is equal to 540 ranking base temperature, base pressure those are appearing in this equation we know so the Tb base temperature can be chosen in the different units let us say degree Fahrenheit it is 60 and converting it in degree ranking it becomes 520 R similar for the base pressure it is 14.7 psia.

So let us see what information is given and what we need when we are considering or predicting the gas flow rate in a unit of cubic feet per hour and the expression we are having on the right hand side big expression are there and the unit are made in such a manner the QH will give us cubic feet per hour or the desired unit of the Q that we want from this equation. Now what others is not given F we will talk about this P1 is given P2 is given T the average temperature is given length of the tube is given gamma g is not given.

So we can see the gas that is getting transported from point 1 to point 2 is having certain specific gravity let us say that is point 7. So now this information is also known to us now it remains compressibility factor diameter is also known. So two times relevance F and Z bar so let us talk about the Z bar it is a compressibility factor we understand from our natural gas properties class. How to calculate compressibility?

To calculate the compressibility we need to know the average temperature and average pressure average temperature is given we can assume the average pressure just taking this P average = P 1 + P2 / 2 and when we do so we can get the value of average pressure that is 350 psia. Now knowing the average temperature average pressure specific gravity of the gas by using the methods like the Bril and Becks method we can calculate the compressibility factor.

So let us assume I did that calculation and got the value of compressibility factor as 0.9298 now the f remains in this expression otherwise I can get the QH by putting every value in this expression now question comes how to know the F from the last class or the class in wpr we understand the F depends on the roughness of the pipe. So nothing is mentioned so far about what is the called roughness of this pipe.

Let us say this information is also given to us that is f salient the roughness of the pipe that is equal to 0.0006 or not given we can always assume this as one the value and next to know the F to know this friction factor we can go to literature and depends on the Reynolds number or the depend on the flow regime we can calculate either from the chart or from the expression given in the literature how to calculate the F value.

To know the friction factor value we need to know the Reynolds number to read the Moody's chart F salient by D we calculate because F salient given to us D is the internal diameter of the tube. So we can calculate F salient by D no Reynolds number so let us see by the definition in the desired unit that we discuss in the last class the Reynolds number expression appears like 0.48 gamma g q / mu D.

Gamma g we know q is in cfh the unit we want in cubic feet per hour mu is in centipoise and D is in inch. So diameter is also given to us in inch and based on that Reynolds number expression we will get the numerical factor because of adjusting the units for parameters appearing in this expression. Now question comes gamma g is known to us D is known to us what about q because we are supposed to calculate q.

And what about mu the Viscosity of the gas that is being transported from 0.1 to 2 through this pipe which is having roughness 0.00006 and the pressure at one end is 500 pisa other hand 200 psi. We can calculate the viscosity of the gas knowing the average temperature and average pressure of the system. So let us see if I use that method of the CKB I got the value of viscosity S1.34 centipoise.

So I know now viscosity now q is not known to me and to know the Reynolds number or next extent to know the F that is appearing in this expression I need to know the Reynolds number that is where the iteration is required because we are going to calculate the value of q with the help of Reynolds number while Reynolds number depend on q for that we can do the iteration processer what we can say?

Let us assume some value of q at first instance 500000 is chosen the flow rate is CFH after assuming this value we calculate now the Reynolds number value and when we are calculating the Reynolds number we can put in this expression Z in 1976 which is recommended in most of the turbulent flow condition where how to calculate the F that is just depends on both roughness of the pipe or relative roughness of the pipe that is F salient by d and Reynolds number.

So now we know the relative roughness of the pipe assuming the value of q we know the Reynolds number after putting that Reynolds number in this expression and they are F salient by D value I can calculate the value of f using this expression and when it is done I got some value of F now this f should be put in the expression of q whatever the form we are taking like Weymouth equation other that depends on this F.

So this is general equation when the expression for F is not included it is just calculated separately and we have chosen this Gen 1976 model to calculate the F putting the F value along with other parameters we know all then we can calculate the Mu Q value now match the Q value which is assume is matching with this calculated value of Q or not. If not then we can take this is the next assumption repeat the processor calculate the Reynolds number this is should be RE capital or should be there.

So we can calculate again the new Reynolds number value Mu F value and Q Mu value and we got this improvement it is not 500000 it is 664000 + in the second round it got improved to some new value when we put this value in the third trial perform the same calculation got the another new value comparing this old and new still there is significant different we can go for one more iteration. Now comparing these two values the different is only 9 CF per H.

So we can consider this okay otherwise we can go for some more fit iteration and to calculate the value of Q and that is where the iteration processor is required because our F depends on Reynolds number and Reynolds number depend on Q and we are calculating Q. So after doing this thing we came to know what is the flow rate that with that the gas is passing through this tube that came out as 0.67 million cubic feet per hour.

Similar exercise can be done considering the other expression for F like what Weymouth have done we can consider that equation of Weymouth also and calculate the QH value. In that Weymouth consider only diameter is responsible for calculating the F value not the Reynolds number or the relatively roughness of the pipe. Some numerical coefficient appearing in that expression account for the relative roughness of the pipe as well as for the flow regime.

If we do so we can chalet the value of QH with the method of Weymouth it is coming out 0.6 million CFH. So still there is a difference between the value which we can calculated by iteration processor or by Weymouth equation but in a range of like 0.67 and 0.6 Weymouth equation is a good approximation because we do not know this method is correct or not for that what we can do we cannot go to Moody's Chart and see the Reynolds number is varying in the range of 1.7 10 to the power 6.

In that range we see it depends on F silent d also not on the Reynolds number so both the expression this expression consider the relative roughness that is why it may be consider as relatively more accurate compared to Weymouth equation we are getting and that is why this Gen 1976 model is recommended for the turbulent flow region because it predict how the F value is changing with respect to effective roughness as well as Reynolds number.

With this example it is clear how to set up the equation how to perform the iteration to get the missing parameter in this problem it was Q H itself which was supposed to be calculated when the other conditions are given to us.

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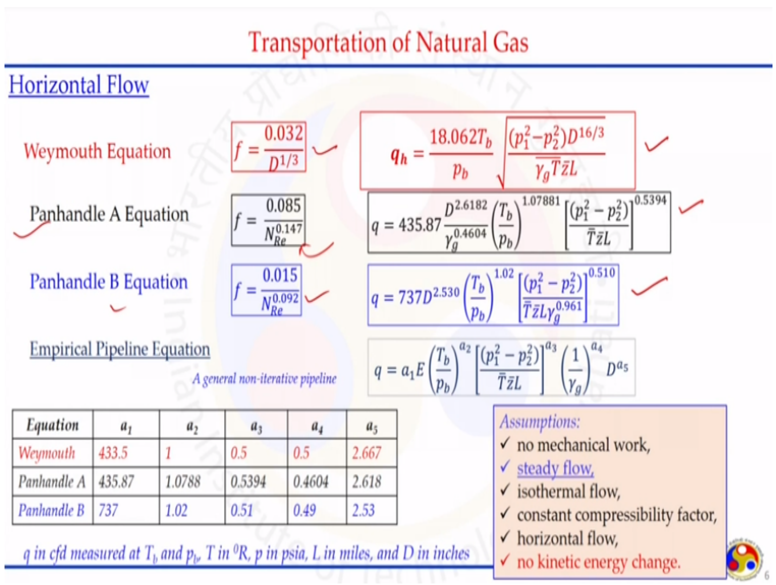

In the last class we could set up the expression for different form of pipeline equation like the Weymouth which consider how f is changing with respect to diameter only. Manhandle equation it is not diameter alone but it is in the form of Reynolds number the expression is given which was further modified and other expression given putting all these three F in the previous equation or in the general equation we can get this expression.

We could also write the empirical pipe line equation that says in the general form we can write in manner where a1, a2, a3, a4, a5 could have some numerical value and the numerical value are according to the equation that is Weymouth equation Panhandle equation and Panhandle

B equation. So with this background let us start how to set up the line or pipeline system in series parallel and loop manner.

It is often required the through put should be increased previously for example a particular place is having X demand now the demand in that particular is increased how to modify the pipeline system what design system or design approach should be chosen to meet that demand at consumer end for that either the entire pipeline system may be modified or just the modification can be done in the existing pipeline system to meet to demand or the meet to through put that can be transported from the existing pipeline system.

This is required the setup of parallel series or looped pipelines system not only to meet the through port but for the cleaning purpose also or the pipeline those may go through pressure de-rated condition means those become old and they cannot handle certain amount of the pressure may be that portion of the pipeline or the pipeline in that reason can be put in the loop or in series or in parallel condition to meet the throw port at the other hand.

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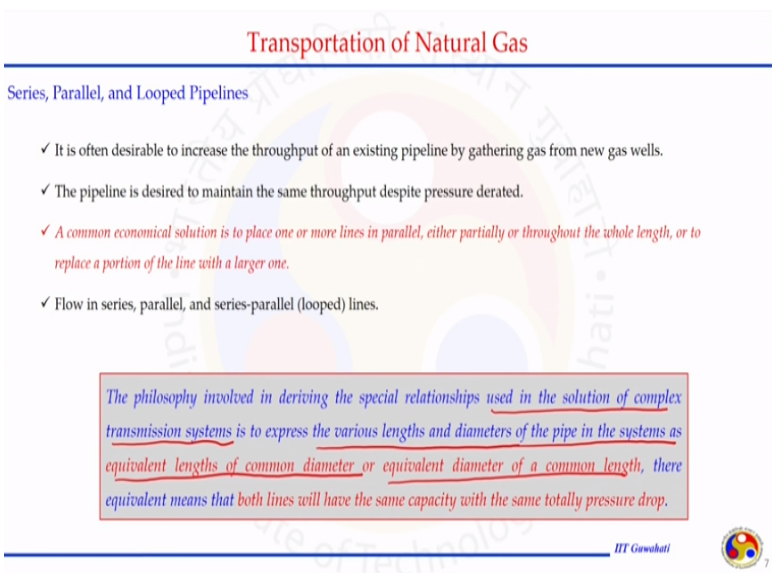

So a common economical solution is place one or more lines in parallel either partially or throughout the line to replace a portion of the line with a larger one that can be done. So the setup in this manner either partially or fully we can go with the series parallel and series parallel that is called the combination of and it is named as a loop pipeline system. The general philosophy about setup of the pipeline in series parallel or in a loop manner involved in deriving the special relationship used in the solution of complex transmission system that express the barriers length and diameter of pipe in the system as equivalent length of common diameter.

So the equivalent length of the common diameter or equivalent diameter of common length their equivalence means that both the line have the same capacity with the same total pressure drop. So when we are setting up the series parallel and loop pipeline system because of different reason meeting the throw port considering the cleaning option under the philosophy like the pressure at both the point should be maintained as well as the capacity should also be maintained.

The equivalent length of common diameter or equivalent diameter of common length should be considered in this case what happens when we are changing certain part of the pipeline we will see how by changing that portion how the total flow rate or the capacity of the gas that can be transported will get change. There could be N number of combination that can be setup in precious case.

For example we were having 150 miles long pipeline we setup the mathematical equation to calculate the QH. Similar between this 150 miles pipeline between 0.1 and 0.2 certain portion may be put up for the series and parallel common option is series parallel combination and increase in the throw port. This is required to meet the demand at the other end.

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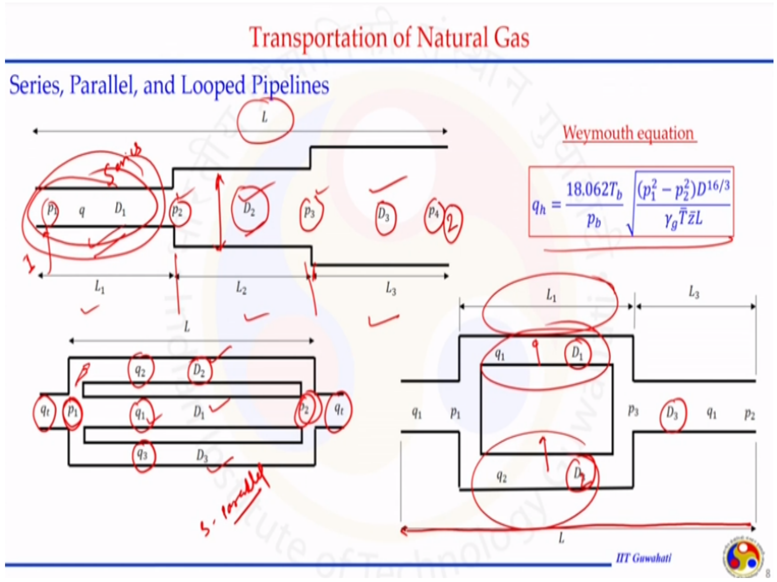

So let us understand how the series parallel and loop parallel are installed so for example in this series this is what the series pipeline system where initially we are having the pipeline like this which is having the diameter D1 pressure P1 at the one end and pressure P2 at the other end or if I say pressure P1 at this end point 1 of interest and this point of interest 2 where the pressure was P4.

So maintaining the pressure P1 to P4 can be installed the pipe line in a series manner where the part of this total length L is divided in segment. Let us say in three segment L1, L2 and L3 so this L2 part is replaced with higher diameter let us D2 and we are going to have the larger diameter pipe for this length segment L2.

So the L1 is just remains as the original pipeline L2 segment is replaced by D2 and because of the diameter got change the pressure at the outlet of the 2 will get change let us say it is P3 and similar at this point the another segment of this entire length L that we can say L3 that segment is also replaced with a little bit more larger diameter tube.

So let us say this is D3 and the pressure at the end of this P4 so when the single line was there pressure was P1 to P4. Now the size has been changed the diameter has been changed at two locations at two segments L2 and L3 we are have the pressure distribution like this inside of it this is a series combination where the capacity can be increased. In parallel case what happens we are having this total Q2 that is flowing between pressure point P1 to P2.

Now this pipeline of diameter D1 and Q1 was put under the parallel condition between these two point another pipeline of diameter D2 with a flow rate Q2 has been setup and because of that the flow rate in this pipe becomes Q1 and another pipeline is also installed parallel Q3 so we are having the 3 parallel pipeline system here and condition are maintained in such a manner P1, P2 is same.

You want to see the capacity increasing because of putting the pipeline in parallel with two difference diameter not necessary the diameter of the new pipelines always higher than the previous they may be smaller diameter D2, D3 may be the smaller diameter but in complete parallel pipeline we are having the entire length L has been put in the parallel mode with the pipe of different diameter or the same diameter can also be there and with length L.

While in the looping system so this is D2 should be D2 and this is D3 so initially a pipeline of D3 diameter certain segment of that let us say this is L1 segment has been transferred to parallel line option where we are having the two parallel branches of the different diameter D1 and D2. So for all these combination we can say for the particular segment let us see in a series this segment again it is pipe with relative roughness with F value the pressure difference is air the pressure different it is having the diameter non gas is getting pass through this section we know the gamma g of that we can complete compressibility factor we can calculate the viscosity also.

So now we can set up the equation for each segment that is appearing in all this combination or example here in series we can set up this equation for simplicity we had considered the Weymouth equation but similar problem solved with Panhandle equation either A or B or any other equation the difference is in the form of F is calculated.

So let us see in series we can set up for this and this each section L1, L2, L3 similar we can do for this we can do for parallel and loop line. Let us understand one by one how we can do that.

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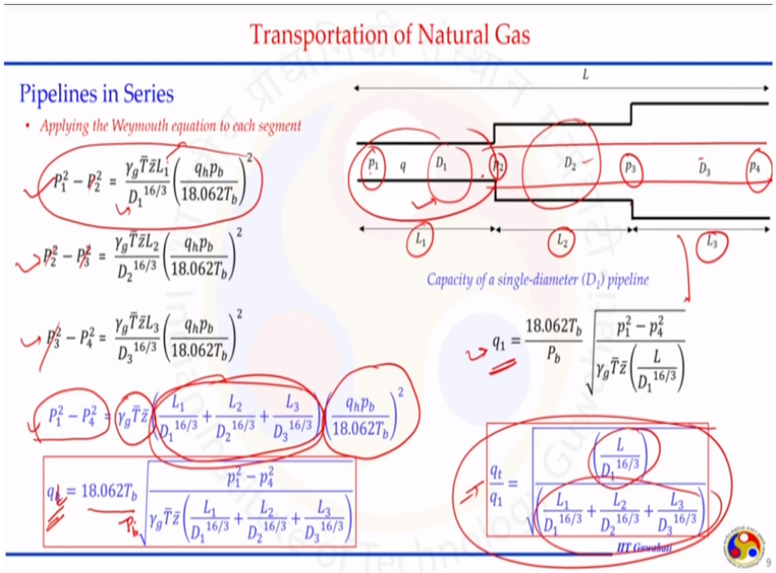

So when the pipeline are in series similar symmetric diagram is here the pipeline L1 which is the original pipeline we are having he L2 and then we are having the L3 three segments. Different diameter, different pressure drop but the common point is here where both the different diameter pipes are getting joined we are having the common pressure P2 similar here P3.

So for this case first segment, second segment, third segment all the informations are given to us we can set up let us apply the Weymouth equation for each segment for this pressure drop P1 to P2 we can set up the equation this is the same equation we just converted that from Q form to P1 square – P2 square form just taking everything on the other side we can set up that thing. The advantage is for each segment we can set up in terms of pressure so for segment 1 it is P1 to P2 everything is ok here the only difference is diameter D1 and L1 others are same.

Because QH is flowing from all this okay now we are having the second segment 2 where diameter is different D2 length is difference L2 the pressure difference is 2 to P3. So it is from P2 to P3 we can setup the equation like this similar we can do for the third segment now when we can do this for 1, 2, 3 segment we can do it for N number of segments it does not matter 2, 3, 4, 5 we understand how to set up the equation for each segment of length L1 and diameter D1 we can do the expression.

Now when we sum all this three P2, P2 will cancel out similarly P3, P3 will cancel out so this term will cancel out and we will left with P1 square – P4 square on the left hand side, right hand side this is a common part that come out separately this is also common part temperature compressibility gamma g that is not going to change with the diameter in length of the pipeline this part will be different then the single segment equation that says the form of L / D in the Weymouth form we are going to get the addition of L1 / D1 to the power 16 / 3 similar for L2 similar for L3 segment.

Now we can convert this beck again the form we want that is QH after doing that we will see we are getting this expression. This expression should also to have PV in the denominator. So we are having the QH form when this segment of a pipeline or port in series now we are having the equation Q also with us that says for example the entire pipeline it just having this D1 diameter and spread for all L length. So originally this was like this equation.

And the pressure P1 was here P4 was here that is still there P1 and P4 we can set up the equation for the same adjusting this equation is not required because we are already having in the form of QH now what we can do we can divide Q / QH just to see how much gas capacity got increased by changing certain segment of the pipeline with a larger diameter here we have chosen D2 and D3 are larger than D1 if we divide this Q that we can say QT with this Q1 we are going to get this expression.

This expression says on the numerator you are having some L and D and in the denominator you have having the L and D for all three segments. Now just to know how much gas capacity increase we do not need to do all causation did in the previous example how to calculate compressibility factor F value and other thing we can just know how much segment of a original or existing pipeline has been replaced by other diameter pipe we can calculate the increase in the gas capacity we will solve one problem to do that.

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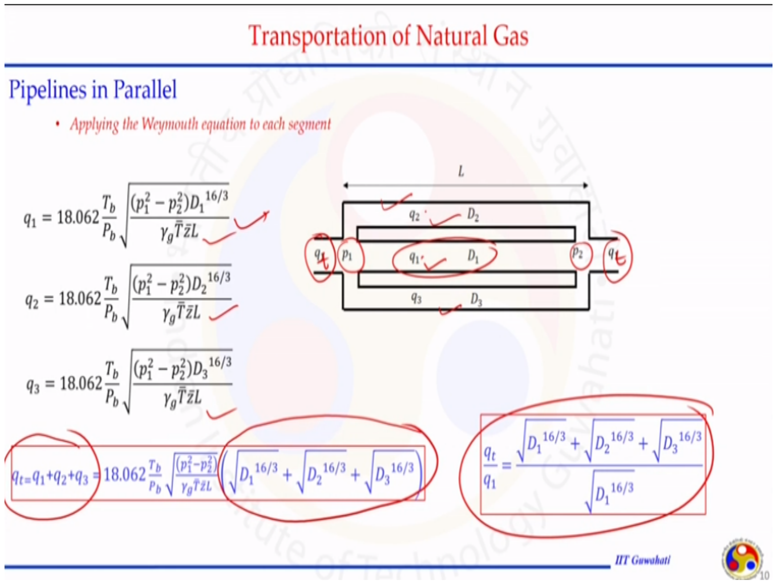

Let us go with the parallel mode in parallel mode what happens we are having this again P1 and P2 at 1 end and 2 end we can set up the equation for this pipeline Q1, Q2 and 3 for each pipeline which is having the different diameter different flow rate we can calculate Q1, Q2 and Q3. Now this Q should be QT that total flow rate QT can be calculated by doing the summation all three pipeline flow rate.

So this is Q1, Q2, Q3 if we sum up we get QT = Q1 + Q2 + Q3 and after doing this summation we see the L is common in all three expression this is just the diameter that is different so we are going to get the diameter in this form is getting sum up because the different diameter pipeline are in parallel the total Q should be deepening on the diameter of the pipeline installed parallel to the existing one.

Similar we can do to understand or to calculate how much increment is happen in terms of gas capacity we can divide this Q2 considering this Q1 is there that is already we are having this expression. If we do so we get this expression and in this expression we see even the length is cancelled out because all the three lines are occupying the entire length L of the existing pipe line and it just a matter how what size of the diameter pipeline in installed in parallel to the existing one that is going to calculate the increase that is going to be in the Q value.

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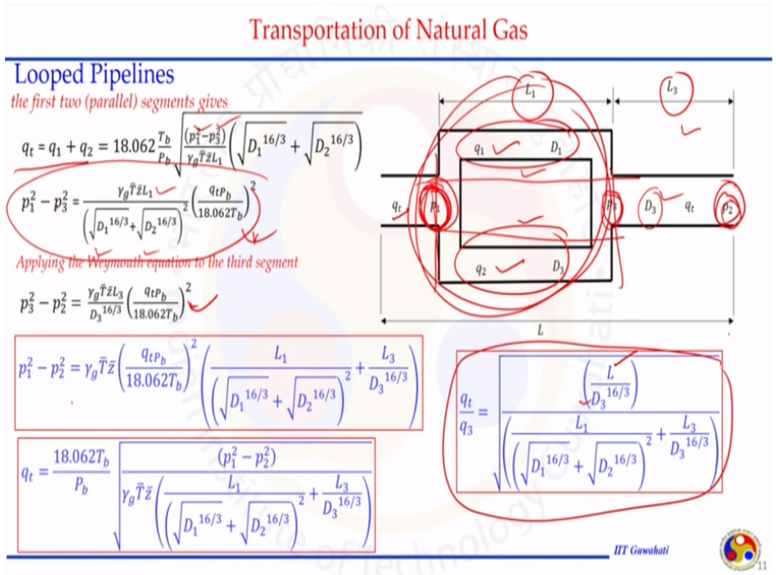

Now when we are having a system where we are installing parallel as well as series of option and calculating or calculating the increment that going to be in the flow rate we can apply the similar principle of series and parallel here so for example between these two point we are having the parallel combination and for that we understand how to calculate the total flow rate that is Q1 + Q2 will tell us the total flow rate between pressure P1 and P3.

So here total flow rate is Q1 + Q2 and that is between P1 and P3 pressure are adjusting this equation we will get this form and in this form we are having this L1 and that L1 is here D1, D2 both are in parallel will go to denomination this is same mode as we did in the parallel line. Now this system is in series with this L3 pipeline here is the L3 segment. So we can setup again the Weymouth equation for the third segment and in this form we are going to get P3 – P2 equation.

Now we can replace this P3 square when we add up both the equation the relationship between P1 and P2 so this is P1 this P2. So between these two point P1 and P2 we are having the relationship which accounts for both series as well as parallel combination. If it is considered the parallel mode was not chosen it is just a single diameter D3 pipeline that was originally here we got this expression and when we dividing the QT with the Q3 that is the original flow rate if there is no pipeline is installed we will get this expression.

Again this expression will tell us how much increase can be expected or achieved when we had done this arrangement. Here this equation depend on both length as well as diameter because it is having the combination of series and parallel.

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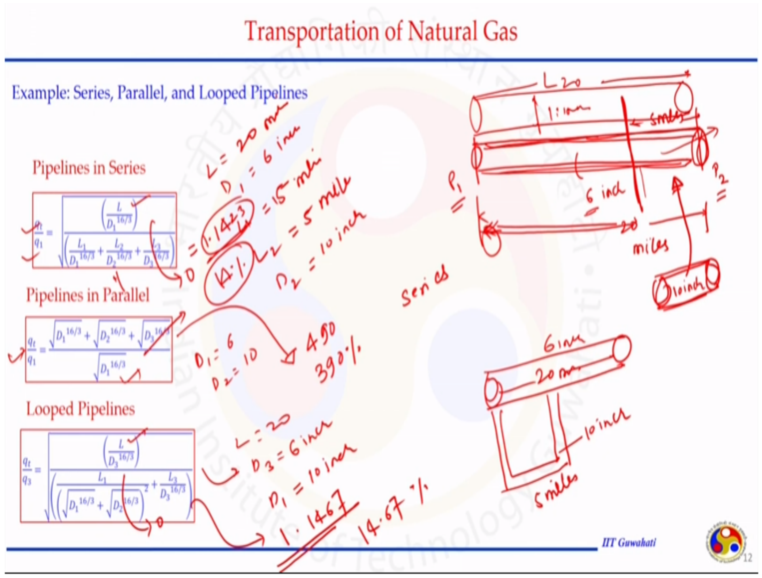

So we can understand this with the help of one example that says a pipeline can be put in series parallel and loop pipeline here could be N number of option that we will discuss in next slide but for example the pipeline is under consideration and this pipeline is having certain diameter and certain. So I can write the diameter this is having 6 inches and the length from here to here let us simplicity as in the small length this is 20 miles.

Now this pipeline under this consideration we are not going to put other detail like what is the gamma g? What is the relative roughness? Because those are not appearing when we are talking about putting the system under the calculation for calculating increase in gas capacity of the pipeline while we are installing series parallel or loop pipeline system along with this one. So let us say this pipeline of 20 miles with diameter 6 inches was subjected to consider series parallel and loop system.

We need to know the pressure at this end P1 and at this end P2 and here we are assuming the P1 and P2 or little bit far from both the pressure and delivery point this is the segment which is not getting affected by the compressor or delivery point this is just a segment of the pipeline of the long pipeline which we counted as the 20 miles in the length and 6 inches in diameter. Knowing this pressure P1 and P2 the pipeline was subjected for series case.

In this series consideration the 5 miles of this pipeline let us say 5 miles is taken out and instead of that a pipeline of bigger size let us say this is having diameter of 10 inches is installed. So this is 5 ML 6 inches diameter as ben taken out and the same length 5 ML large diameter 10 inches is installed here. You want to see the increase in the Q that is going to be by doing this arrangement. So we are having the expression QT / Q1 here L original length So that is L = 20 diameter D1 that is the original diameter that is 6 inches and this all is in the same units we do not need to worry about the converting into unit system this is 20 miles.

Now L1 which remains after making the system under the series so we are having the L1 after taking 5 miles it will be 15 miles and L2 which is the next pipeline size will be 5 miles. Now what we can do we need to know the diameter D2 we have this D2 = 10 inches. Now we have the expression there is no D3 we are just the segment in 2 parts L1 and L2 when we put everything in this expression this expression came from Wey mouth expression when we put in this expression we get the value of this expression as 1.1423 that says after replacing the 5 miles pipeline of 6 inches diameter by the same length pipeline of 10 inches diameter.

The increase in gas capacity if 14% there is could be another possibility where we are saying parallel to this pipeline of 20 miles another pipeline of 10 inches diameter is installed parallel to this. In this case the length is same 20 and the diameter of this parallel tube is 10 inches so now let us look the parallel case the pipeline design in the parallel mode D1 will be same 6 inches D2 will be 10 inches there is no D3 we are having and D1 is again 6 inches in the denominator.

When we put in this expression we can get the numerical value of this and that is comes out as 490 it means 390% increase in the gas capacity occur when we put 10 inches diameter pipeline of 20 miles along with 6 inches diameter pipeline. So large increase in the capacity can be expected because the diameter is large it is more than 390%. Loop pipeline system so instead of putting everything is in the parallel what we can do this is original pipeline of 20 miles long and 6 inches entire.

We can say a part of it is put under the looping system or under the parallel mode and in that case let us take the same value it is 5 miles that was put under the looping of 10 inch diameter. We know the expression for looping system where L is again 20 D3 is the original diameter that is D3 = 6 inch and D1 is = whatever the new pipeline has been installed that is 10 inch 5 miles is considered to put in the parallel mode that why it becomes the looping system and when the calculation is performed this the quantity or numerical value comes out as 1.1467 it means 14.67% increase in the gas capacity is calculated when we are have this kind of the looping system.

So I think with this example it is clear how we can perform the calculation and calculate the gas capacity is changing when we are having the series parallel and loop system not necessary we are always going with bigger size or always looking for higher diameter size it might be possible we can reduce the quantity that is transported by reducing the size of the diameter. But that is very rare case mostly it is we want to increase the gas capacity because day by day the demand at the other end of natural gas is increasing.

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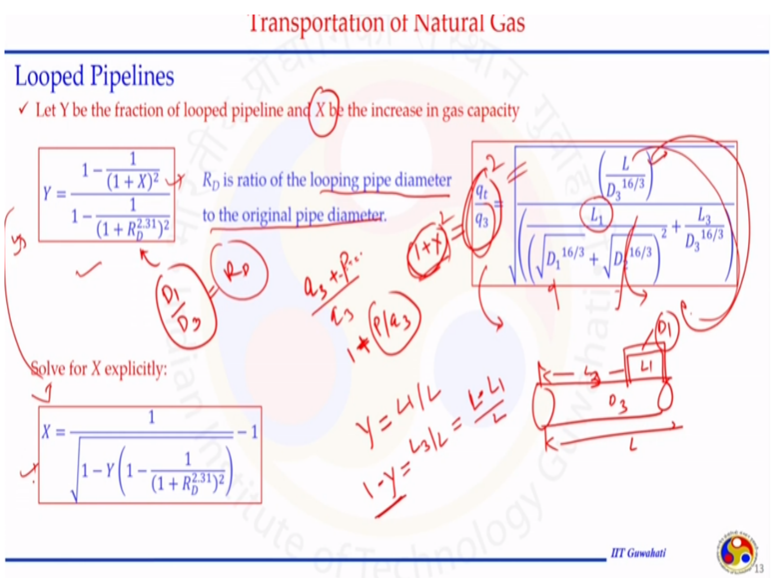

With this example I would like to go with the general expression for looped pipeline system the general expression is the required because every time if we are performing the calculation that can be done with the help of a computer but every time you have to choose the pipeline you have to choose the length and diameter you are going to replace.

Instead of that the expression of the previous loop system can be put in a general form where you can different value of the length different diameter and can have a system or a graph where you are having the understanding of if this segment of pipeline is replaced by this diameter how much gas capacity can be done. And that could be a good exercise when you are given a task of designing the pipeline you can consider the several combination of that and based on the economy involved or the cost involved in replacing the pipeline and appropriate decision can be made.

So let us go in this expression which we had in the last slide for the loop pipeline system here length is the original length L1 is the segment that put in the looping system the number of looping system we are having we have to do it for each looping system. Let us go with the one of the simplest case where we are having the looping system just only certain length of the adjusting pipeline has been put in the parallel with a different diameter D1.

So the original it is having D3 now it is put in parallel with a diameter D1 so the length of this is L1 and this entire length is L and this length will be L3 let us say the same rotation we are going. Now this QT /Q3 = what Q3 + increment Q3 is the original without any doing modification in the pipeline. Now whatever the modification is done that is here divided by Q3 and that modification of that the increment is happening in the gas capacity it can be represented by a terms.

And that terms let us say we are having some P term and this will be 1 + P / Q3 it means this term represents the increase in the gas capacity we can denote this with the general term used for this is X we can say this QT / Q3 = 1 + X. Similarly the by with the fraction of loop pipeline so how much pipeline segment has been put in the loping system we can define Y = here like L1 put under the looping system.

So L1 by L is my Y and similar we are having another segment here that says what about L3 by L simply L3 = L – L1 divided by L so we can write for this is 1 – Y. Now if we put for this X + 1 and we can take this in the denominator this term will not be there putting for why we can go further with the expression or the desired expression we want here is another term appearing is RD that is the ratio of the looping pipe diameter to the original pipe so here we had done the looping with D1 divided by the original diameter is D3 and this is represented by RD.

So when we are taking this in the denominator L will get adjusted by the by ratio and ratio D1 / D3 will be adjusted by RD if we put everything here we are going to get this expression and in the explicitly form of the X can be adjusted this equation and we are going to get this expression in the form of X. I think it is clear this can be written taking the square root out of here we will get Q2 / Q3 square and then we are going to get X + 1 square that is appearing here and similarly.

I think this can be done as exercise we will get first this expression after doing the adjustment we are going to get this expression in the form of X and with the help of this expression you will get the relationship between X, Y and RD. X represent the increase that is going to be in the gas capacity Y what part of the adjusting pipeline should be put in the looping and RD the ratio of the diameter means that segment which is put under the looping what diameter should be chosen we can put different and can generate the result as done in the book are taken this plot and that says the effect of loop line on the increase of gas flow rate for barriers type diameter ratio.

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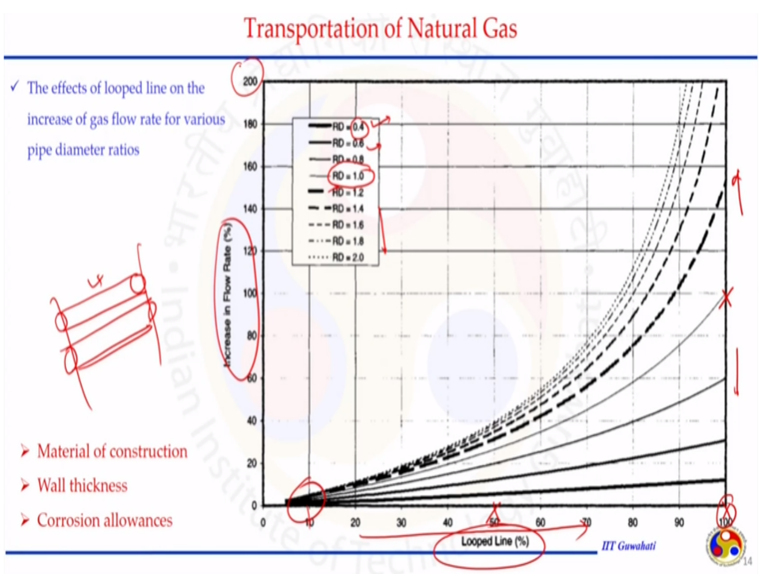

So where it is done different diameter that says has been chosen so see here it is not always we are choosing the higher diameter RD lesser than 1 means smaller diameter has been chosen to understand the looping means RD value higher means larger diameter is chosen the increase in flow rate means plotted out Y axis while considering how much length percent is put under the consideration.

So let us consider some of the case where we are having RD = 1 means same diameter was put in the looping and when we are having this diameter of the existing pipeline similar diameter was put for entire length. Simple understanding is same diameter is put for the same length between this point to this point the capacity should be doubled and that we can see from here for RD = 1 when 100 % was put in the consideration it is here where we are having the 100% increase in the gas capacity.

And when we are having this parallel diameter at a lesser size we are going to get the increment there but not up to doubling the capacity while diameter of larger size which is used for the loping we will always get higher and that is happen in the previous example when we put 10 inches parallel to 6 inches 390% increase was obtained. This can also be done when different segment not necessary entire thing put in the parallel line some part of it 10%, 20%, 30 % is put under the looping system.

We understand by seeing the expression or by common understanding when the small part is put under the looping the increment will be less as we are increasing the part of adjusting pipeline to be looped the percent of gas capacity increase will be higher and it goes like beyond even 200, 300 previous example we had seen 390% also considering the other parameter the path line the material of construction the gas capacity which is required to be increased the system can be chosen from such kind of the designing and depend on the other factors the existing pipeline can be put in the looping or based on this the new pipeline can be lay out with the series parallel combination.

With this understand I think it is clear how to use pipeline system to transport the natural gas from one place to another place how to understand the relationship between flow rate pressure fluid properties and the size of the pipe is used now further it is series parallel and loop pipeline system. Other parameters should also be considered when we are designing appropriate pipeline system.

For example material of construction is considered it is one of the mechanical properties that designed what type of material should be chosen it depends on several factor the pressure the pipeline is going to experience the terrain it is going to face the climate it is going to pass through the wall thickness is not to consider again several factor the collapse criteria and other things the material or construction decide the wall thickness and the corrosion a line is not considered what we did is simply pipeline equation that is give us the flexibility to calculate the gas capacity that can be increased to a desired level has been discussed in this class.

Other mode of the transportation are also there other than the pipeline for example CNG and LNG depend on the source form where the natural gas is being transported to destination means where it is going to be used. The path line it is going to phase it is onshore offshore it is having different political reason to pass or other factor determine the mode of transportation the other than considering the technical part.

Pipeline design is still the first choice compared to others but the other modes are also getting popular because of their own advantage.

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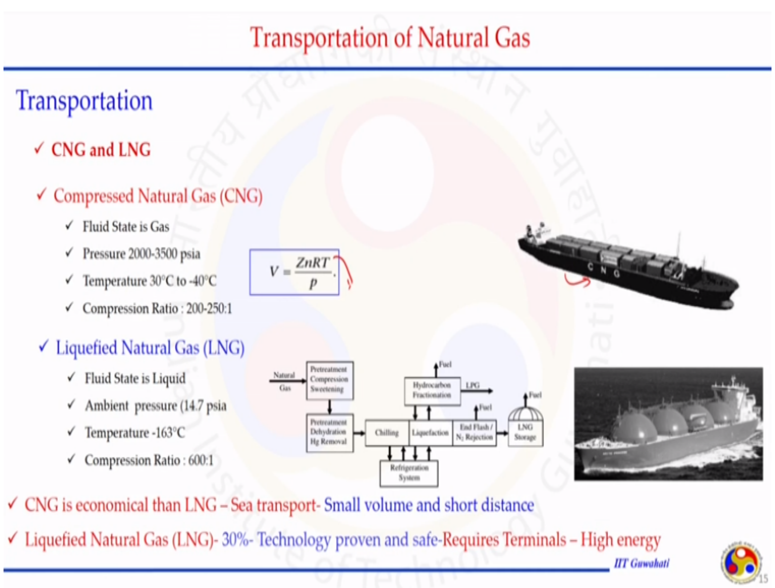

For example CNG and LNG area so the mode of natural gas transportations where CNG stand for compress natural gas in this state the gas remains in the gas phase but under very high pressure condition that varies up to 2000 to 3500 psi. In this pressure range the gas is still in the gaseous mode the temperature can be from 30 degree C to – 40 degree C again reducing the temperature the more volume can be accommodated in the same vessels further reduction can be done in the temperature but not up to the level where it is going to be converted into liquid form.

And we can compress the gas by increasing the pressure to 2000 to 3000 psi the compression ratio or the volume of the gas occupied in a vessels compared to under standard condition is 200 to 250 ratio. So 200 to 250 times the gas can be compressed and it will be in the gaseous phase only there are several uses of compress natural gas so for this C transportation system compress natural gas is becoming a choice because it can be transported in a tanker kind of the system those are less costlier and compression ratio is not that high as compared to LNG but the facilities required to compress the natural gas transport in natural gas is more economical compared to LNG.

If we reduce the temperature little bit more down even the compression ratio can be improved while in case of LNG liquid natural gas the fluid is cooled down to certain temperature that is around – 163 degree Celsius and the gas get converted into liquid it is not a chemical reaction something it is a phase transformation is happening the gas is report under the refrigeration cycle and it is going to be chilled and de-chilled where it is going to in the liquid form.

The pressure is ambient pressure or around 14.7 psi temperature is -163 Celsius and under that condition when it is going to be liquefied the compression ratio is very high 600.So the 600 times natural gas can be stored in the same volume which is consider at standard temperature and pressure condition. That is the advantage of LNG that by LNG is consider as the technology proven and safe but both the processes are having their own features.

For example the compressed natural gas can deliver or can be chosen and option to deliver the natural gas when the small volume for the short distance is supposed to be transported while the LNG is considered for a longer distance and last quantity is getting transported CNG also need a special type of the tankers sometime they called the C transportation mode is called the floating pipeline while LNG the terminals are required the places are required where the natural gas can be liquefied so this LNG facilities are required.

And then it is need very special type of the tanker through which it can be transported by maintain the temperature – 163 degree Celsius and at both the places the source places from where it is getting transported to the place of receiving end the facilities or the terminal facilities should be available to accommodate the natural gas transportation. So both the modes of transportation like CNG LNG depends on several other factor like the facilities infrastructure available the quantity supposed to be transported how many rounds can be made the loading and unloading facilities are available or not.

Compared to CNG, LNG is still having a higher significant higher share in transportation actually after the pipeline LNG is second choice but because of the uses of CNG in different fields or in different sector like for the vehicles for the local transportation the CNG form is being considered very significant option or prominent option.

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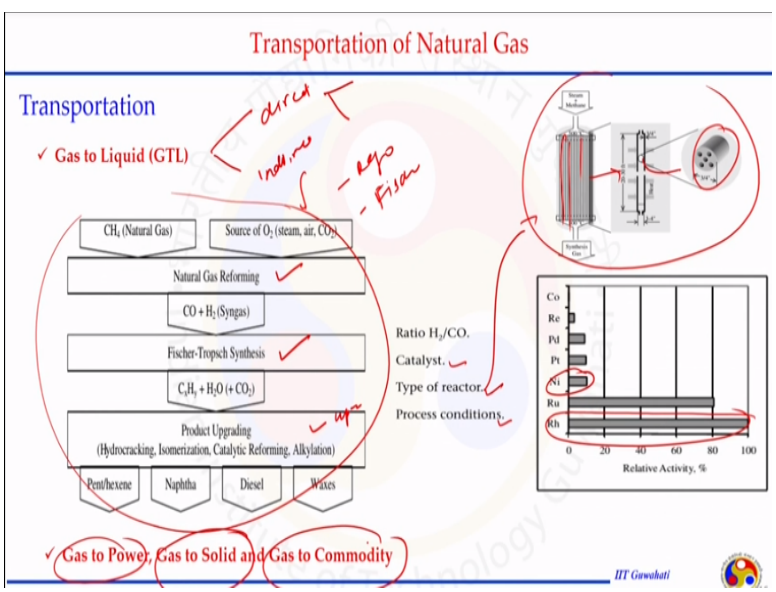

Another mode of natural gas transport could be converting natural gas to liquid the process is called GTL in this process the natural gas that is mostly methane is gone through this theme reforming process or just a reforming process depend on the oxygen source provided to this reforming process happen it may be the steam reforming the oxygen source may be just O2 can be steamed can be CO2 or can be here the product of natural gas reforming or CO and S2 that is called the thin gas.

The CO and S2 can further go through the chemical process that is Fisher-Tropsch synthesis and can go through the polymerization reaction and can produce higher hydro carbon compounds those higher hydro carbon compounds are liquid at the ambient temperature and pressure condition and along with those CXHY compound H2O or CO2 or the source of oxygen gets released.

The product CXHY can be upgraded further to have the desired product that could be hexane Naphtha grade, Diesel grade or Waxes. There are other form of the liquid those also be produced from the natural gas like DME de-methyl ether any additives that is used in the crude oil. So the difference in the LNG and GTL is in the LNG low chemical reaction happen just because of the temperature the gas is going to change it is phase from gas to liquid.

While in GTL process it is a chemical synthesis process or chemical conversion process with the help of catalyst and appropriate operating condition like temperature and pressure in particular type of the reactor source of oxygen we can convert this through reforming and further applying Fischer- Tropsch synthesis process into the desired liquid compound.

Research is still going on to make this process more viable more economical because it depends on the type of the reactor several reactor configuration like if it is shown here when we are having several channels one of the channel is shown like this and within this channel we are having this catalyst packing. Several type of the catalyst can be used nickel is considered as low cost catalyst compared to other.

But better activity is observed with RU and RH so the catalyst plays major role in this type of conversion and lot of research is going on towards this direction to make GTL more economical and feasible. Other mode of the transportation can be converting gas to power is called the indirect mode where electricity is generated with using the natural gas and natural gas is contributing to with the energy demand.

Even in the GTL process there could be two ways direct and indirect way so the direct conversion we get low selectivity and low conversion that is why it is not economical or it is not in the practice much but in the indirect mode this is the mode which discuss three steps are involved reforming Fisher – Tropsch Synthesis. So this is reforming Fisher Tropsch Synthesis and this is upgrading so the direct mode is different and the indirect mode are getting the liquid.

It is not direct conversion we are getting the liquid it is not direct conversion to liquid we have to perform some chemical reaction to get the conversion of gas to liquid. Other mode gas to power converting natural gas to electricity gas to solid crystalline form and gas to commodity converting this in to some commodity material then transporting them by a local transportation mode like the truck rail, and other mode.

So with this brief discussion of CNG, LNG and GTL I would like to conclude the discussion on transportation of natural gas by different mode and we had more emphasis on pipeline design system with this I would like to thank you very much for watching the video we will meet in the next lecture thank you.