Natural Gas Engineering
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Module No # 02
Lecture No # 09
Gas Well Testing

Hello to everyone, in today's class lecture we will understand the testing of the gas well. We will go through the concept of why well testing is required, what are the advantage it will offer? and how it is going to be helpful in managing the natural gas production as well as the business concept.

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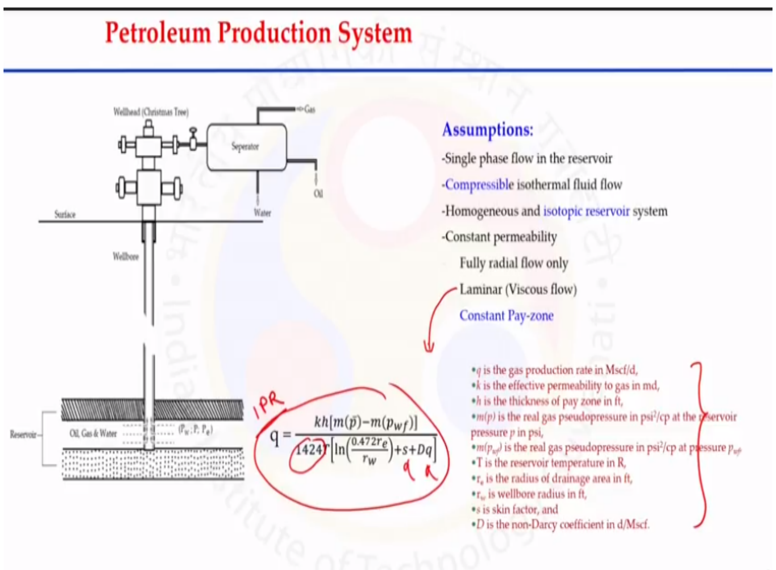

There are several methods through which the gas well testing can be performed. In fact gas well testing itself is a three hours per week a semester course. But in today's lecture we will try to go through some of the important process through which the gas well testing can be performed and some of them will be discussed just in the form of overview and some will be discussed in detail considering the mathematical analysis of the gas well testing.

So before we go further let us understand the petroleum production system what we did so far we had developed the relationship that we called IPR. For this bottom part of our entire production system we said the flow is happening from the reservoir to well bore. Because of the pressure draw down and the flow rate is related to pressure gradient as well as the properties of the fluid, properties of the formation and the geometry of the formation.

For example, k Permeability, h pay zone thickness, T Temperature and other two parameters are here s and D. And the expression appearing here will take a different form depend on the scheme or the approximation approach adopted to establish the relationship as well as the numerical coefficient here will depend on the unit system chosen to represent each parameter appearing in this expression.

To derive this expression we had assumed certain things the assumptions are like the flow of the fluid is happening in a single phase that is gas phase in our case. And the flow is happening in a radial direction on this all the fluid from the drainage area of the reservoir of a pay zone thickness h is travelling radially towards the well bore. The fluid or the gas is compressible in nature reservoir properties are constant which means it is homogenous reservoir and isotopic in the nature.

We also assume laminar flow but later on after developing the expression we had converted this expression to account for the skin factor as well as non-Darcy coefficient. That is account for the turbulent flow that is happening near the wellbore reason and the constant page on thickness.

So ultimately we had received this expression if you are having the properties or the parameter appearing in this equation if this parameters are known to us we can establish the relationship between q and Pressure draw down and that will help us to predict what will be future of the gas well production system. But it is not easy to get all these properties like permeability, page on thickness known every time.

And for that there are some other schemes, those are called empirical schemes. Those are based on the experimental field data have also been established.

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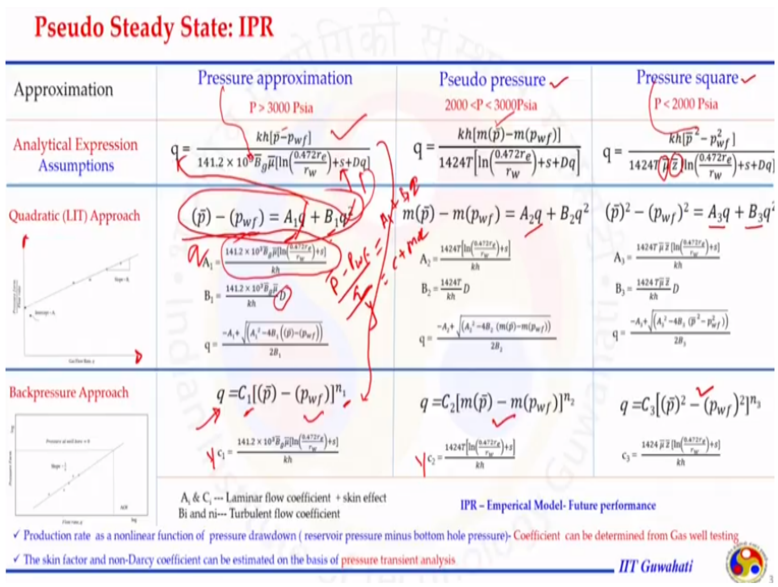

The Pseudo steady state system with similar represent can be written for the transcend condition and steady state condition. But let us take the example of Pseudo steady state because that is the condition through which the reservoir produces most of the time. So the analytical expression we can write them in terms of P approximation, Pseudo pressure approximation and Pressure square approximation.

We know how to choose this approximation, so here I have written P greater than 3000 psia it means we can take the pressure approximation because during this pressure reason the multiplication or the combination of the fluid properties Mu and Z remains constant. Pseudo pressure, it is the most accurate approach that is account how the fluid properties are changing.

From one reservoir condition to, from one pressure condition to other pressure condition how this transition is happening and if the pressure range is between 2000 psi to 3000 psi Pseudo Pressure approach should be adopted. And in the other case when the pressure is very low less than, very low means less than 2000 psia the approximation for the pressure can be taken in the form of square forms so that is pressure is called Pressure square approximation.

When we take this expressions solve the general IPR curve IPR equation, we get this analytical approximation where in case of pressure approximation we are having P in the numerator, Pseudo pressure we are having mp and Pressure square we are having P square. And by combining the parameter non-parameter or the combining one form of parameter to the other form of parameter we can get the coefficient parameters appearing in the expression.

For example in a pressure approximation we are having this Bg, Bg is a volume formation factor that has been converted the reservoir condition using the value formation factor conditions. Similarly in mp approach we could eliminate fluid properties appearance in this occasion by combining this in a real Pseudo gas pressure like in mp, while in p square approach we are having this fluid properties Mu and Z, but those are in the form of average properties.

So further if we know the values of this parameter we can establish the relationship but in most of the cases as I said these knowing these parameters accurately is a difficult task and even knowing this parameters what exactly is happening in the future, for example, how this skin formation deposition is happening, is there any changes in the Darcy coefficient D is appearing over the time. The gas well testing would be performed to know all these changes happening over the time.

But before going to gas well testing let us understand in more detail what exactly happens to this parameter when we are going to perform those testing and several empirical correlation has been proposed. We are going to discuss two mostly used correlations, first is quadratic or laminar inertia Turbulent approach LIT approach. In this if we adjust this equation carefully we can see the case may end up like having the 2 coefficient A1 and B1 and in the quadratic form q, because of this and another q square will come because this q in the D will multiply with the q on the left hand side you will get q square.

So ultimately what are we going to get, we will get quadratic equation which is relating pressure with q and other parameter those are appearing in the expression like permeability, Pay zone thickness, properties of the fluid all are combined in the form of A1 and B1. We will discuss later on what is A1 and B1. But similarly can done for the form of pseudo pressure approach and pressure square approach.

Just to distinguish this I had numbered them A1B1 for the pressure A2B2 for the Pseudo pressure and A3B3 for the Pressure Square approach. Identically they are representing the same kind of the phenomena that is happening. So what exactly we can do using this empirical model we can predict the future performance. So for example we are performing the field test if we can know A1 and B1 B will be having the IPR correlation and using this inflow performance relation we will predict the future of Gas well.

For example, at a particular bottom hole pressure if I am running my well what will be the flow rate at that particular bottom hole pressure as well as what will be what is the potential of the reservoir that is AOF maximum production we can achieve with this well can be established by knowing this coefficient.

This is not only the approach, there is another approach the back approach or called the simplified approach. In this backpressure approach the expression can be written in this form where everything which is like A1 is here in the form of C1 1 by even C1 exactly and the n1 is corresponding to this B1.

This expression can also be written the backpressure approach can be written in the form of Pmp and P square approach. So considering these two approach if we can calculate the coefficient for example in the quadratic A and B and in backpressure C and N, we are having the IPR equation. That is the case on record to develop the inflow curve. How to get those things, so before going how to get those things let us understand what is A1?

So if you match with this you will see A1 is account certain parameter including the skin factor. So whatever the changes is happening in skin factor and other properties of the (()) (09:55) will be reflected by the A1 while B1 is corresponding to D. It also includes some of the parameter where primarily it is because of the D if D is not appearing the non-Darcy coefficient is not present in our equation there would not be any B1 terms, similar for B2 and B3.

IT is a quadratic equation we can use the quadratic formula to calculate the root of this equation we can calculate like –B +-B2 -4AC upon 2A principle, we can get the value of Q at any particular flow rate if we know what are the values of coefficient A1B and at a particular pressure bottom hole pressure we want to calculate the flow rate we can do by solving this quadratic equation.

Similar can be done for this backpressure equation C1 represents like similar to what A1 represents here and in fact it should be 1 by C1 represent the similar thing and the value of n1 is corresponding to the turbulence or non-Darcy coefficient. If the value is n1= 1 it means it is fully laminar flow condition, there is no turbulent effect if the value is towards 0.5 it means it is a fully turbulent condition is appearing, so the value remains between 0.5 to 1.

If the value is greater than 1 there is some problem in terms of like some fluid has been removed at a faster rate from the reservoir then the expected or if it lesser than 0.5 it means there is some error in data collection. Other than estimating this value by knowing the parameter as it is appearing here we can do by the gas well testing. As I said while doing the gas well testing what we can do we can establish some type of flow pattern or pressure versus flow relationship in a flowing well and using that relationship we can estimate the value of A1, B1 and similar C1 and n1.

Corresponding to pressure square approach and mp approach the parameters can be estimated. So this equation particular equation is having two constant. For example, the LIT approach is having A1 and B1. So to know these two constants we have to have a data at least two conditions, that we are having the two condition data like at a particular bottom hole pressure Pwf1 the flow rate is Q1.

And the second condition is Pwf2 the flow rate is Q2 we can put those data here we will get two equation and we can solve those two equations to get the value of A1 and B1 similar can be done in the log form we can do these similar condition for the backpressure approach. If we are having the more data we can plot linear relationship and the slope and intercept can give us the value of A1 and B1.

That we will discuss in detail later on when we will be doing the gas well testing how to get the relationship or different set of the parameter of Q versus Pwf. By seeing all these thing we can understand the production rate is a non-linear function of pressure draw down. Pressure draw down is the difference in the pressure this reservoir pressure – the bottom hole pressure and the skin factor non-Darcy coefficient can be estimated on the basis of pressure transit analyser.

The skin factor and non-Darcy coefficient comes into picture near the wellbore region. So the skin factor is something that some deposition or some damaging happening to the well we are having the skin factor positive skin factor and sometimes when the fluid is travelling from a larger radius to a wellbore means a smaller radius the turbulent may get create.

So what we can do we can conduct some pressure transient means the pressure is changing with respect to time near the wellbore region if we can perform such kind of tests we can get value of S and Darcy coefficient in that region. And for the other cases when the flow is happening under Pseudo steady State condition we can perform the test and can get the value of coefficient A1B1. These values can also be get with the help of when we are having transient condition.

So we will discuss all these in the next slide. But let us see what I can represent here so if I can adjust the equation, this equation is a quadratic equation but if I can take q from this side and put here. So what I can do pressure draw down divided by flow rate is equal to so what I will get P bar - Pwf / q = A1 + B1q. So if I can plot this y = c + mx what I will get a linear relationship.

And from its slope and its intercept I can get the value of B and C. B represent for non-Darcy and C represent for other parameter those are responsible for this flow to happen like the permeability and other parameter. Similar can be done in a log scale so this is on the (()) (15:02) scale this well. The quadratic approach while the backpressure approach we can take the logarithmic of equation and by plotting on a log scale pressure draw down versus log versus flow rate on the log scale the slope will give us 1 / n value knowing the 1 / n value we can calculate the value of C.

When the pressure draw down and flow rate several factors include in that in that equation if the parameters are known we can solve it analytically otherwise we have to Empirically model and with the help of running the gas well testing under different condition we can calculate the parameter those are appearing in the empirical models like quadrated and back pressure equations and knowing the our IPR equation we can calculate the desired thing which we want to know from this particular gas well.

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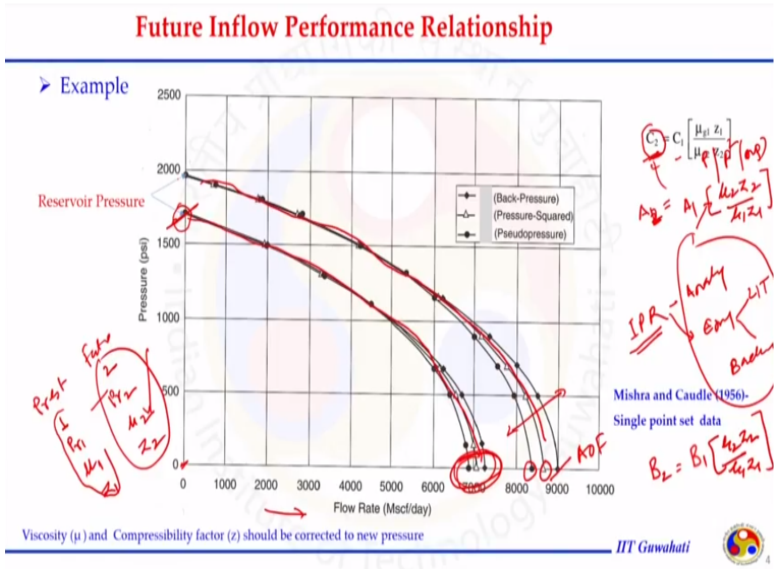

So next why it is important as I just mentioned so if you are having the IPR equation and that IPR has mentioned in the last slide could be in the form of analytical expression or could be in a empirical. Empirical is having further classification in LIT or in a backpressure equation. And each equation like this three set of equation can be written with the three approximation P, P square and mp approach.

So now we are having a set of the equation those represent the similar thing what exactly is happening, how to know which equation is good to be used to predict the future of the gas well. One of the parameter that is we already discussed in the IPR class that says how to choose a particular approximation. I just summarized in the last slide also if the pressure is less than 2000 P square approach, if the pressure is greater than 3000 psi p approach and anywhere in between 2000, 3000 and or any other condition if we can afford the computational facility to calculate the mp we should always use the mp approach.

So if you see here the pressure draw-down, is pressure a pressure is going down the flow rate is increasing. So what we can predict at a particular Pwf what is my flow rate? What we can say if my Pwf is at a reservoir pressure that is 2000 Psi I would not be having any flow rate. My flow rate is 0 but if the Pwf is little lower we will get the flow rate. And when the Pwf is 0 backpressure is at means 14.7 Psi we are getting the AOF condition.

Absolute open Flow condition is the maximum flow rate can be achieved from a particular value. And you can see the value is different with a different method used backpressure, pseudo pressure and pressure-squad approaches are plotted here for these set of data and we can see the AOF value is varying with the all three cases. And that is very important to know which one is the correct value because that decide the supply and demands (()) (18:19) of the natural gas production system as well as the facilities those are installed at the surface are being utilised effectively.

So this is one observation that need to be test which model is presenting the correct way and second is observation if reservoir pressure after sometime is down means it has been reduced from 2000 to somewhere around 1700 what you will see the IPR curve is getting changed. It is getting changed not only in terms of the value but you can say the AOF value will also get changed. So knowing in future we understand like reservoir pressure goes down over the time.

So what we are supposed to do we are supposed to calculate the coefficient of the empirical equations just to understand what exactly changes are happening in the reservoir formation or at least other parameter like may be the constant page on thickness, the permeability if you are not doing something external. The important part how the reservoir pressure is declining and when the reservoir pressure is declining what is the maximum production rate that can be achieved, and what is the potential of the reservoir under that condition can be estimated.

To do so we need to recalculate A1B1 every time and that may be a tedious job because gas well testing impose certain restriction. The gas well is not producing during that period or it is under the flow condition that is not optimised to use the surface facilities so we are just flaring the gas. So to avoid all those things we can do, if the gas well is tested under one condition we can just correlate the coefficient to the other condition.

So for example in a back pressure equation when we are talking about the future and we say how the coefficient will get change C2 we can simply calculate that C1 multiplied by the properties of the gas being produced from the reservoir. So here if you can see so in my present time if the condition is 1 and my future condition is 2 at this condition my reservoir pressure is PR1, here it is PR2.

What I can say here the gas is being produced is having viscosity, average viscosity you can say Mu1, here it is Mu2, Compressibility is Z1 and here it is Z2 and some other parameter those are responsible for that. What we can say if from present to future we are going what we can do, instead of calculating the coefficient again running the gas well testing we can just replace the coefficient like this.

So C2 = C1 multiplied by the viscosity compressibility factor in the numerator and Condition 1, means present condition divided by the future condition. While the Coefficient A1 will be in a reverse way, so the A2 will be, future Coefficient A2 will be A1 multiplied by Mu2Z2 upon Mu1Z1. Similar B2 can be B1 Mu2Z2 upon Mu1Z1. So just knowing the properties of the natural gas that is being produced at this condition or in future when we are talking about at what rate this will be producing, like for example here the 1700 we can directly correlate the parameter and put the expression and again you can see there is a deviation in the AOF value being calculated with a different methods.

Mishra and Codel in 1956, they understood this and they said just a single data set can be used to have the future production without knowing much about the changes those are happening for that Pwf bottom hole pressure and the average reservoir pressure should be normal or the maximum condition 1 of the conditions should be known, either the maximum reservoir pressure condition or Pwf along with reservoir pressure condition.

So using that Mishra and Codel expression we can also predict the future performance of the IPR.

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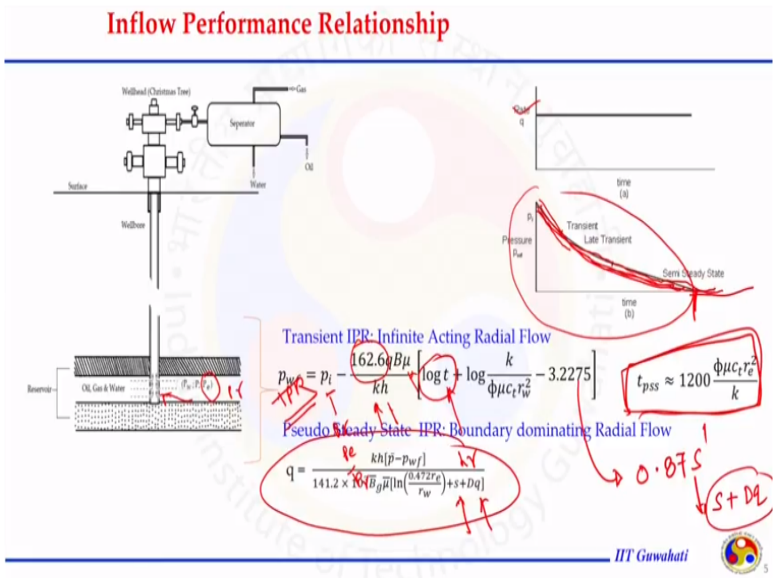

So what exactly we did exactly, let us go to understand the gas well testing will be done. So in this domain when the reservoir is at PE sometimes we write as PR the flood is travelling to the wellbore under the radial conditions we called it IPR curve. And initially when the well just start to open we are having this kind of pressure relationship with respect to time.

Safety gas well is put under a constant flow condition like q so what happen with respect to time initially you are having the transient then the late transient condition and then finally it reach to semi state condition. We have discussed this in detail in our IPR lecture. But what is important here so when we are testing our gas well under this time frame when the pressure is changing we have to use the transient equation not the pseudo steady state expressions.

And when the pseudo steady state condition reach we have to use the pseudo steady state equation those we had discussed in detail couple of slides back. So transient equation, what happen during this time? So we are having the relationship with the PI Pwf means bottom hole pressure, PI is the reservoir pressure, different notations are written. So this is equivalent PR, or I can say PE or P bar R minus some numerical coefficient.

Again numerical coefficient depends on the unit system has been chosen here. Other units chosen here are the US field Units system except this T that has not been discussed so this measured in power. So considering that we are having the transient IPR equation for Infinite acting radial flow condition and this is happening exactly here. And the time when it will reach the pseudo steady state condition can be estimated with the help of this.

But when we are reaching the pseudo steady state condition the time terms disappear from the expression and after doing the adjustment for that condition we get this expression. Here you may see the s and DQ are here, similarly there can also be s and DQ and we can write this 0.87 S prime, S prime include for both scale + non Darcy effect. So either we are using the transient, if we are in a transient region or we using the pseudo steady state condition when we reach the pseudo steady state condition.

The time taken to reach the pseudo steady state can be estimated approximately using this expression. And all these expression could be written in P square approach, mp approach as well as P approach as written.

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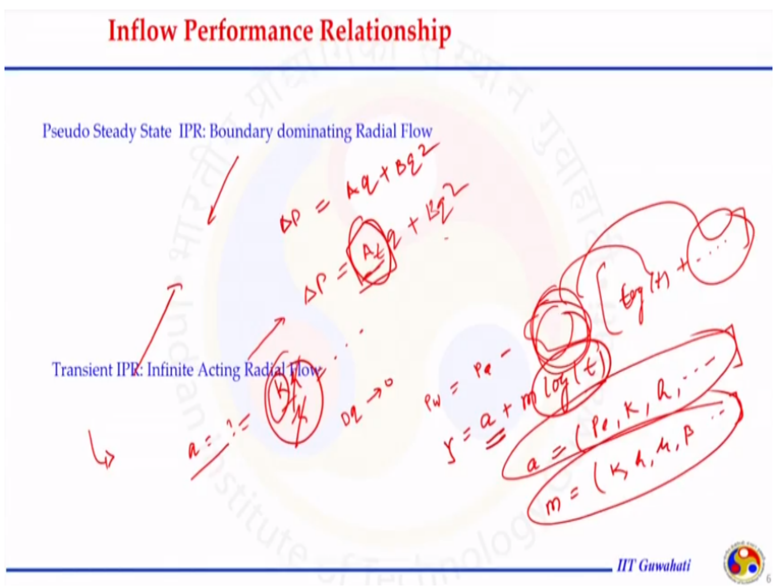

So let us say understand the transient condition and the pseudo steady state condition in little bit in more detail. So in transient condition which is acting infinite acting radial flow what exactly happen, we can adjust the equation and say for a case of when there is no non-Darcy effect this tends to 0. Our equation can simply be written Pw = Pe minus some numerical coefficient, sometime term is here in form of log t + some terms here.

And after doing the adjustment we can write this equation in the form of y= a+m log t a is having this expression, this multiplied whatever is here and m is this multiplied by here. So what is this here? We are having a is a function of reservoir pressure, k, h and several others. Similar m is also having the coefficient appearing here that is having the k if I am correct k, h, Mu, volume formation factor and others.

So if we can run this at a different condition we can estimate the Pwf at a different time, we can put a linear relationship and slope and intercept will allow to have these coefficient value and those coefficient value will allow us to calculate the unknown which is not known to us while the other parameter are known.

For example with the help of a, if we got some value what we can do with the help of a that is having like k, h, Mu + some other term and if we are knowing other parameters we can calculate kh/ Mu and we know the Mu, we can know the h, we can calculate k. So any property which is not known and other properties are known we can get the value of that particular property. And that is why the information of the other gas well is very important.

Maybe the, you are doing the gas well testing for a particular well, the information may not be very important for this particular type of gas well. But this information may be very good approximation for the nearby gas well and some value can be assumed from the nearby gas well used in a particular gas well under testing to estimate the other parameter those are not known.

And by doing the gas well testing further we can validate those parameters estimated are correct or not. In both the cases transient or pseudo steady state if we are not having the non-Darcy coefficient or the turbulent flow we will get the simplified pressure relationship in a linear form and if both are having the turbulent flow the expression will be in a quadratic form.

And in a quadratic form when we are having this will end up like pressure draw down = Aq + Bq square. In a pseudo steady state condition both A and B are the function of the different properties but not the function of time. While in transient case what will happen if we write the similar expression we will get Atq + Bq square. So only A is a function of time that will depend on time because of this time log t is appearing in the transient condition while B will remain the constant.

So whatever the changes are happening with respect to time if we are under the transient condition not because of the non-Darcy flow but because of this At that is a combination several parameter is going to affect the performance of a transient condition. And knowing the transient conditions relationships knowing this At value under different conditions we can predict the behaviour of a reservoir near the wellbore region how the flow is happening in this region?

How the permeability is getting distributed? When we are doing the stimulation of the gas well, we can say how the skin type is has been repaired and other conditions. Those are not known we can estimate with these kind of the analysis. So I think it is clear by pseudo steady state and transient conditions knowing this coefficient will give us lot of knowledge, will give us lot of power to understand more and more about our reservoir.

And that is very much required to predict the future of the reservoir as well as relating this information to the nearby gas well.

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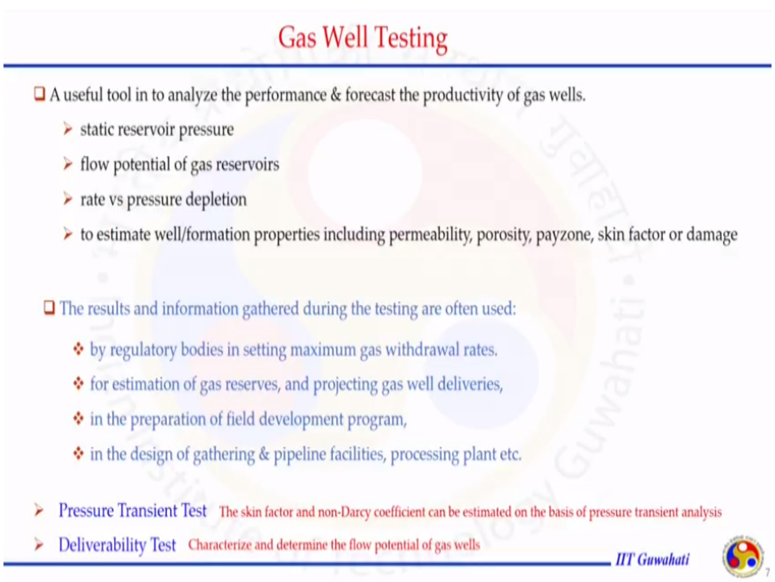

Now let us come to the main topic of this lecture that is a gas well testing. So we understood we can do transient gas well testing as well as pseudo steady state gas testing and knowing the coefficient of the IPR equation we can calculate several properties. So while we do the gas well testing this is a useful tool into analyse the performance and forecast the productivity of the gas wells.

By knowing or the by performing the gas well testing we can understand more and more about our gas well, how it is going to behave as not only in present time but in the future also. The gas well testing will tell us they will provide some of the information such as the static reservoir pressure, what is the static reservoir pressure of the formation, what is the potential of the gas reservoir and what is the maximum production rate we can achieve, the rate versus pressure depletion curve that can be discussed later on the decline curve analysis.

But it will tell us at what rate and what is the relationship between rate and pressure and at what rate the production will decline over the time. This analysis gas well test analysis has already discussed can be used to estimate the well formation properties including permeability, porosity, skin factor, damage any other there, turbulence condition if there are any and the porosity is the storage capacity of the reservoir.

These are important that I said not only to understand more about the well these are also important to maintain the regulation imposed by the authority on production side. So for example the information gathered during the testing are often used by regulatory bodies in setting maximum gas withdrawal rate.

So when you are having a well ready to produce there are certain rules and regulations those are imposed to production part and says the maximum production from a particular well can be maintained not more than a particular value and those not only but authority those also very important because the surface facilities those are installed they are having certain capacity to handle the gas production rate.

If the gas is being produced more than that the only option left to (()) (32:28) the gas into the environment. So the surface facility is not getting damaged or been over loaded so for estimation of gas reservoir projecting gas well deliveries so by doing all these analysis we can understand what is the gas reservoir and what rate the gas can be produced again this will help us to meet the supply and demand relationship and using the surface facilities.

In the preparation field development programs so knowing the behaviour of particular gas will may tell us what is the possibility of the development of field in that region in the design of gathering and pipeline facility as that we already discussed the surface facilities installed to collect the gas through the pipeline from several gas well to a gathering station knowing the behaviour of a gas well.

The gas well testing is classified broadly into two type the pressure transient test and deliverability test. Pressure transient test mostly are done as discussed already to know the nearby formation region the permeability porosity the Darcy effect as well as the radius of the reservoir through which food is being trend towards this and deliverability test easily done to establish the relationship between q & pressure draw down. We will discuss deliverability test in detail.

Pressure transient test will allow us to calculate the properties like-skin factor and Darcy coefficient while the deliverability test will allow us to characterize and determine the full potential of a gas well.

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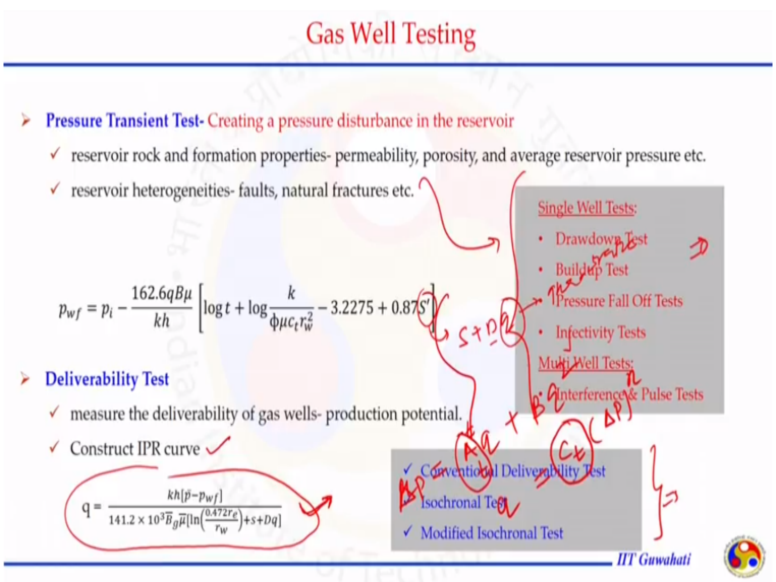

Let see what exactly we do in a pressure transient test when we are having the pressure transient test mostly we are under the transient condition and transient equation should be used. And this is done by creating pressure disturbance in the reservoir once we done a pressure disturbance and measure the flow rate we can see how flow rate and pressure are related with respect to time also and knowing this thing we can establish the relationship either in a linear equation if non- Darcy coefficient is not existing there and or in the form quadratic coefficient.

If terminal flow is happening there we can calculate several other parameters and in deliverability test mostly done under pseudo steady state conditions not necessarily always pseudo steady state condition and deliverability test it measures the deliverability of gas well measure production potential. And here we can get the construction of the IPR curve that allow us to predict the future.

Similar here what I would like to mention here gas prime include for both skin factor plus non-Darcy coefficient in the picture the q also comes and it makes the equation as a quadratic equation. Here this is written in the form of the quadratic equation but s and Dq are not present, it will be not a quadratic equation especially when this D is not present the turbulent flow is not present.

And other things if we are having this equation we can write tP = Aq+Bq2 and in that case this At if we are under the transient condition. And where pseudo steady state condition At will be A not a function of temperature. Similarly we can write for a back pressure equation also where we can say Q is Ct del p to the power n. So this Ct will be a function of time only when we are under the transient condition otherwise it will be a constant value.

So the different test those can be done under the pressure transient test we can classified those as a single well test and a multi well test. In a single well test there are different tests draw down test, build up test, pressure fall off test or injectivity test and in multi well test interference and poise test. These are done under the pressure transient test analysis while under the deliverability test there having the convention deliverability test, isochronal test and modified isochronal test. We will discuss these three in detail while these will be just discussed without having mathematical analysis.

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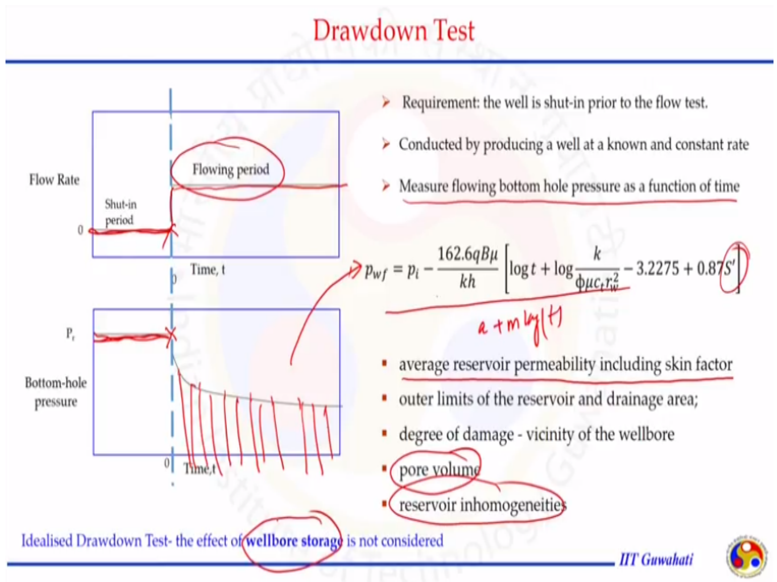

In a pressure drawdown test what exactly we do so gas well which is under the test put under a certain condition for a long period. Long period means when we are sure the pressure is static reservoir becomes constant. It is very important and that is where we can rely on the data how accurate those are as we are sure this condition has been achieved.

And after that period a time = 0 and we do we start producing at a constant flow rate for a certain time period as extended time period can be used. And what happened exactly so when the reservoir under the certain condition the bottom hole pressure was at a reservoir static pressure and when the flow started the pressure will declines here in a certain pattern and we can see the declination is happening in this manner.

So what we can do we can monitor this Pwf value at a different time and this gives us how to use this expression to calculate the a and m this we can arrange in the form of the a + m log t where there is no non-Darcy coefficient otherwise we have to go to quadratic equation. And knowing this relationship we can calculate several properties of the reservoir.

So this is conducted by producing a well at a known and constant rate that i state constant flowing period that is the constant flow rate measure flowing bottom hole pressure as a function of time that we did at the several points putting those data in this equation will allow us to calculate the average reservoir permeability including the skin factor.

Outer limits of the reservoir and drainage area through which area the fluid is travel towards the well because this will say based on the reservoir formation the permeability pressure thickness only will say how the pressure will decline at the bottom hole pressure with respect to time and when suddenly certain well put under the producing conditions. So other properties like pore volume reservoir in homogeneity can also be accessed with the help of drawdown test.

This is a idealised drawdown test while in the actual case the well bore storage also will be there.

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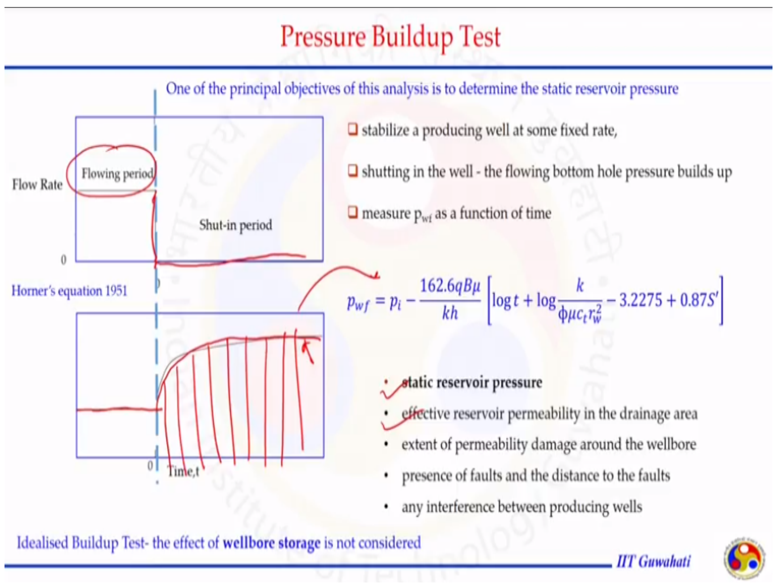

So i think it is very clear putting the time value here we can calculate a and m for a linear system or other case At and B for quadratic form and doing this we can calculate several properties like. If we can know here what is the value of volume for measure factor viscosity and pay zone thickness we can calculate k. And several other what is the pressure draw down is happening because of this can be calculated with the help of this because that will be equal to 0.087 ms.

So if we can know the slope and so if know the pressure draw down and i can calculate skin factor and if know the skin factor i know the slope i can calculate the pressure draw down is happening because of this skin. This gives lot of flexibility for us to understand our reservoir formation. In pressure build up test just reverse of what pressure drawdown is happens here in this kind of test.

In this test what happens the reservoir in the under flowing condition and when we make sure the reservoirs is under flowing condition in this and the pressure is like this here. Ok and suddenly be shut down the well and we shut done the well like this here what happens there is no production happening because the well is under shutting conditions and because of that the bottom hole pressure will start increasing.

Because the reservoir pressure is higher than the bottom hole pressure. So the bottom hole pressure will start increasing and reaching almost steady static reservoir condition. So we can estimate the static reservoir condition with this test also. And this will again tell us how the PWF is changing with respect to time when the well is not under producing condition while it is under the certain period condition.

Same equations can be used for pressure draw down test for this we can get static reservoir properties, effective reservoir permeability, extent of permeability, the boundaries of the reservoir conditions can also be estimated with the help of both pressure build up test and pressure drawdown test. Because both the test provide us how PWF is changing with respective time under the transient condition.

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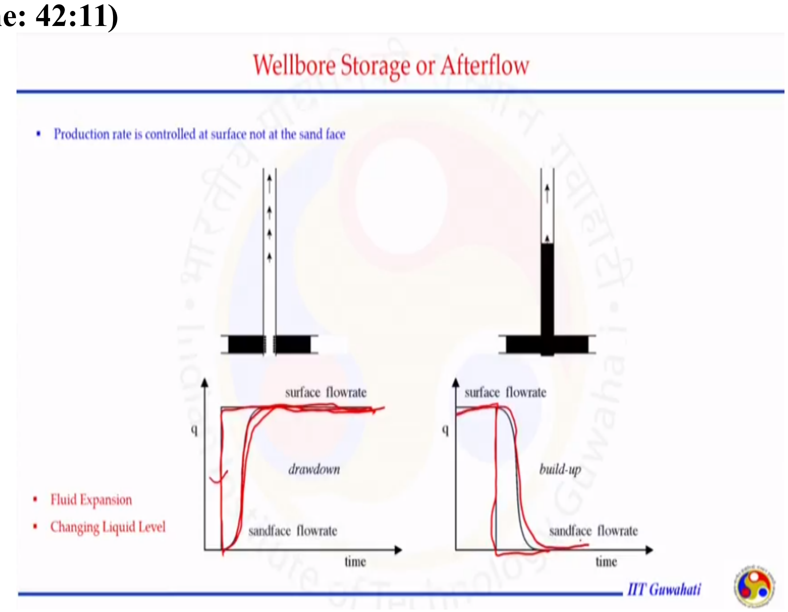

Again here also the wellbore storage is not discussed what I exactly this wellbore storage is so production rate when we say suddenly put under the flowing condition at the constant value or suddenly put under a certain condition is controlled from the surface not from the bottom hole and because of that there is a fluid in the pipe or in the valve or that is affect this actual flow rate that will be achieved.

So for example in case here when the valve is put under the constant flow rate condition is draw down condition. So this is the ideal case but in actual we will get this kind of curve and similar here in a pressure build up test when we are setting down the test the ideal condition should be like this but in actual condition it could be like this this is happen because the fluid in the wellbore fluid expense and happen and changing liquid level.

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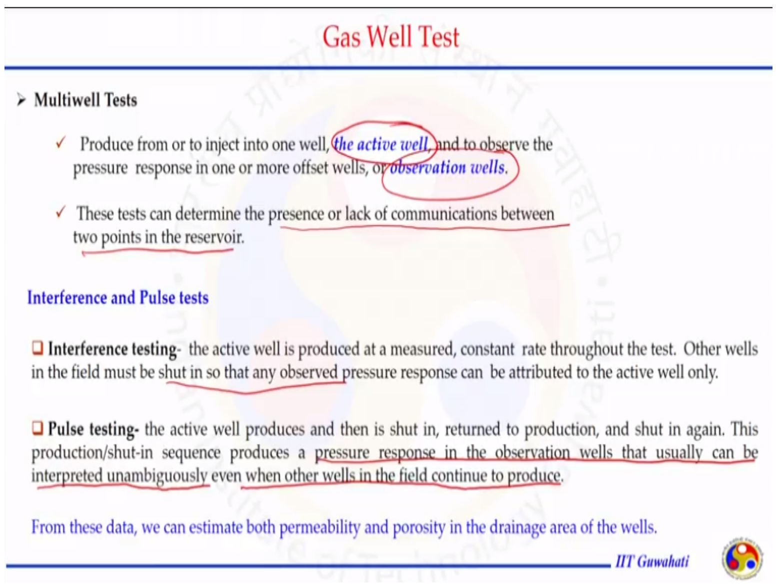

Other test those are pressure transient test they are also classified under the similar conditions as pressure draw down test and pressure build up test. For example pressure fall off test that is similar to what is pressure build up test and injectivity test is similar to a pressure draw down test. With the pressure fall off test similar to pressure build up test allowing the sterilizing at known injection rate, the well is shut in measure Pwf function of time.

So the fluid is injected and just seen how the pressure is building over the time in a pressure fall off test and injectivity test how the pressure is declining over the time in the both cases Pwf is measure as a function of time similar to pressure draw down and pressure build up test and those data can be used to establish the relationships. So the only difference between the previous test and this test these are done on the injection the well.

So instead of we are producing from particular well we inject external gas in the well bore. Through the well bore to the reservoir we observe the behaviour of the pressure Pwf with the respective time. In a multi well test we are in a reservoir field when we are choose the active well that is under the testing and the other wells nearby of this, those are observation well. So we too either work on the active well and observe what exactly happening on the observation well or the other we can be done or something could done on the other wells and how the active well is responding for those changes can be monitor.

So this test can determine the presence or lack of communications between the two points in the reservoirs. In reservoir formation when there are multiple wells are there how they are communicating what is the permeability in this in the region between these two wells can be or in this multi wells can be established. Interference test the active well is produced at measured constant rate thorough out the test.

Other well in the field must be said in so that any observed pressure response can be activated to the active well. The active well is put under conditions other well under the setting conditions and see how the pressure dropdown is happening of the other wells that says how these wells are communicating. In pulse testing the active well produces and then shutting return to production shutting again these production shutting sequence produces a pressure response in the observation well that can be interpreted even when in the other wells in the field continue to produce.

In both the test there is a communication between the active well and the observation well is established and with these data we can estimate both permeability as well as porosity in the drainage area of the well.

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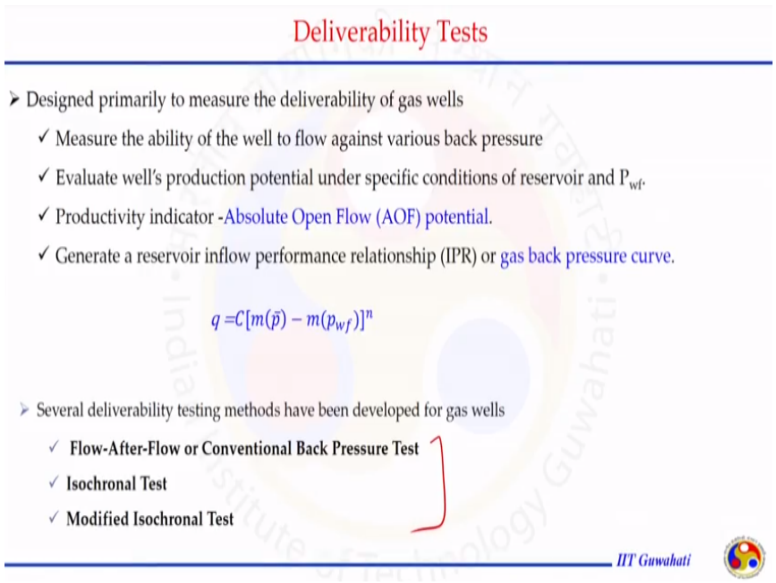

So this was all about the pressure (()) (45:55) test now let us discuss the deliverability test. So these test designed to measure the deliverability of the gas well. Measure the ability of the well to flow against various pressure, evaluate well production potential under specific condition of the reservoir and Pwf, productive indicator is absolute open flow conditions can be measured can be estimated and generate a IPR curve.

So this is exactly what we discuss previously in IPR curve also when we are using the spherical correlation to establish the relationship between the pressure draw down and q by knowing this by perform the deliverability test we can establish the several relationship and that relationship give us what is the potential of the reservoir and what is the AOF of the particular gas well and how to predict the future performance.

Several deliverability testing methods have been developed some of them are listed here those are mostly use flow after flow or conventional back pressure test, isochronal test and modified isochronal test. So I will go through one by one about all the three tested with few example and numerical part may be skip just for an exercise also let see what happens in flow after flow well.

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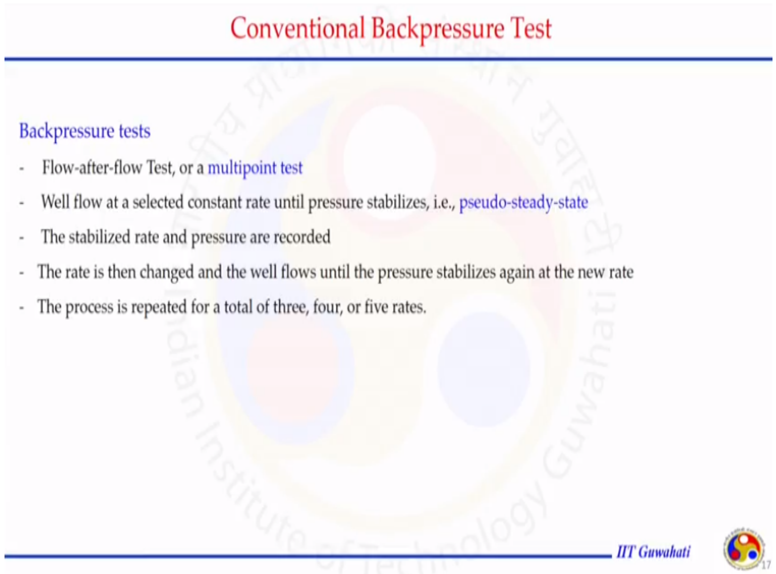

So this is the back pressure test in this flow after flow means multi-point test in which the well flow at a selected constant rate until the pressure established. Pseudo steady state condition the stabilize rate and pressure are recorded and the rate is then changed and the well flow until the pressure stabilize again at the new rate. The process is repeated for a total of 3, 4 or 5 rates depends to step 3, step 4 again. So let see what exactly we do here.

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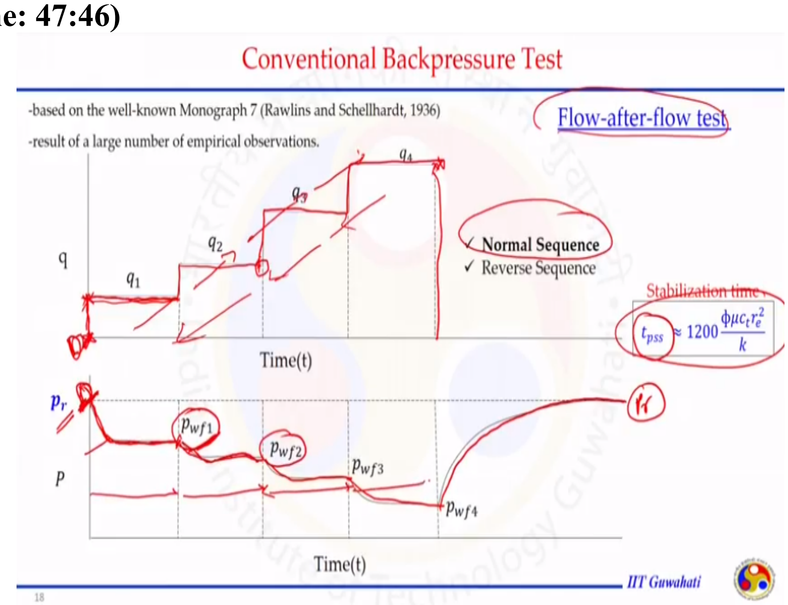

So a gas well was producing under a constant rate for example it was producing under constant rate q1. So in a conventional back pressure test it is also known as flow after flow what is important is the gas, was the gas well was under a conditions of low production. So the gas was here for a sufficient long time and the pressure at the bottom hole was reservoir pressure, the static reservoir pressure. So we are at this point – 1 condition, okay or I can say 0 condition here.

And when the gas well put under conventional deliverability test what we did, in a first step just increase the production rate at a constant rate here. What will happen when we increase the production leave for sometimes, the pressure at the bottom hole will drop down or a constant value of the bottom whole pressure is not achieved here.

So we are saying this is achieved at Pwf1 and the flow rate under that condition was 1, q1. Then further from this point onward what we do, we increase the production rate constant for a new value q2 and in that case again the Pwf will decline and it will go through under transient condition and stabilize at the Pwf2 and P will be having this position here.

Further third step and fourth steps are conducted in a similar manner like this. And when we are at q4, at the end of this production q4, what we will do we will shut in the well again. And when we are shutting in the well, the well will return back to reservoir pressure. So the Pwf value will be PR again. The important of this test is it can be done either in a Normal Sequence or in a Reverse Sequence.

May be the production rate is declining in a each step, instead of increasing as it is done in the system, it is increasing. It may be done in a reverse way when it is declining. But in most of the cases it is expected, it is stabilized that the normal Sequence gives us more reliable data. The important part comes out in this kind of the conventional backpressure test is the time required to perform this test.

So for example here even to start the test 0 it needs to be made sure the pressure has been stabilized within the reservoir and the value is reached as a PR value and after that when we are performing it will go through the transient case and when it reach the pseudo steady state condition we have make sure in each step it reach the pseudo steady state condition and the Pwf should be monitored. Similar in each step should be done. And if it not done the error will be produced in the data and that will give us the wrong IPR curve.

So I think it is clear that in this test we either increase or decrease the production rate. Every time when we are changing the production rate in a step wise manner we are monitoring the stabilized

PWF. The time to stabilize can be monitored with this, can be estimated with this stabilization time expression which say how much time is required to stabilize in each case, like this.

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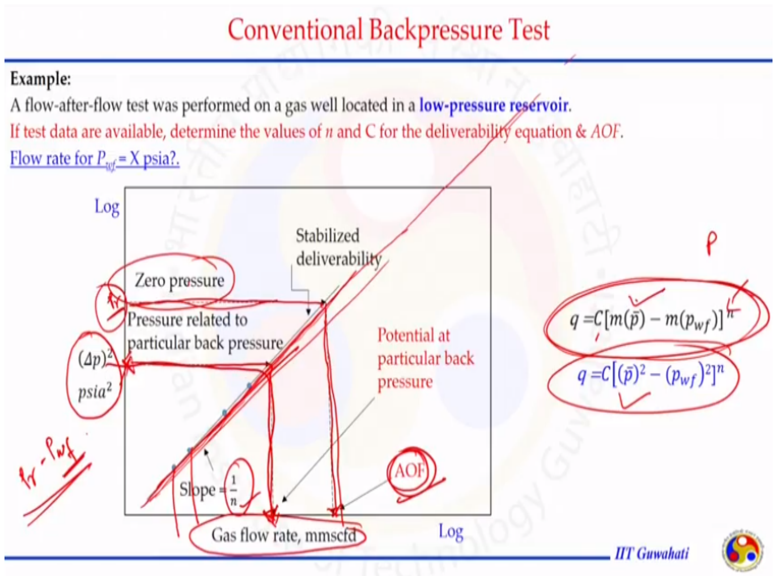

For example here what we are having, we got the data, let us see quickly sorry we got the data how the pressure is achieved at a different flow rate. Knowing those value we can use either this expression or this expression or just a pressure expression, it means either p square approach or mp approach or just a p approach we can plot the data on a log scale and that will give us the linear relationship.

And in this linear relationship it simply says the slope will be 1/ n, knowing the value of n, we can calculate the value of c. What is the important point is here during this curve as this curve is established for a pseudo steady state condition. Pseudo steady state condition means when the radius of investigation is equal to the reservoir is equal to greater than the reservoir radius.

And under that cases we are having the condition where this line can be extrapolated to any condition and that any condition says when the reservoir when the bottom hole pressure reach the reservoir pressure 0 pressure condition is here we are having the AOF value, absolute open flow condition. When this pressure drop down is reaching the 0 pressure. Pressure drop down means reservoir pressure minus bottom hole pressure.

And then when this is bottom hole pressure is zero we are having the reservoir pressure. Under that condition the flow rate will be AOF absolute open flow condition, we can calculate the AOF with this slope we calculate 1/n. Putting 1/n value in this expression we can calculate C for one particular condition and knowing the C value we can establish IPR curve.

In that IPR curve gives us any condition we can say. So for example if the reservoir is being produced at this condition this is the flow rate at that case. Or the other way if we want to produce at this particular flow rate this will be the bottom hole pressure in the reservoir.

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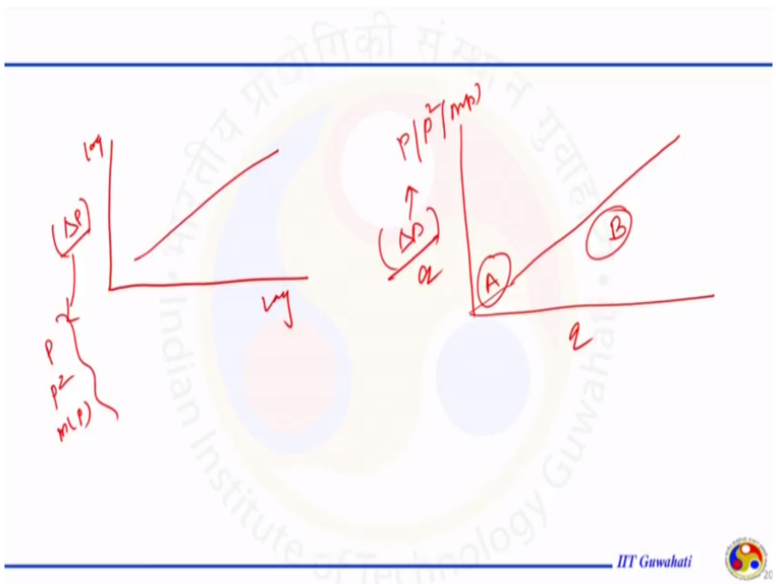

When we say the pressure on log scale is plotted for a pressure drop down del P could be P, could be P square, could be mp difference. We can write in any of the forms. But when we are plotting on the log we are using the back pressure scheme. Similar can be done for a Cartesian coordinate system when we are having this pressure difference, again this pressure difference can be p, p square or mp for divided by flow rate versus flow rate.

We will get a straight line and that straight line simply say this slope will be B and intercept will be A, we can get the value of A and B. And knowing this thing we can also establish the IPR curve in the form of LIT or the quadrated approach.

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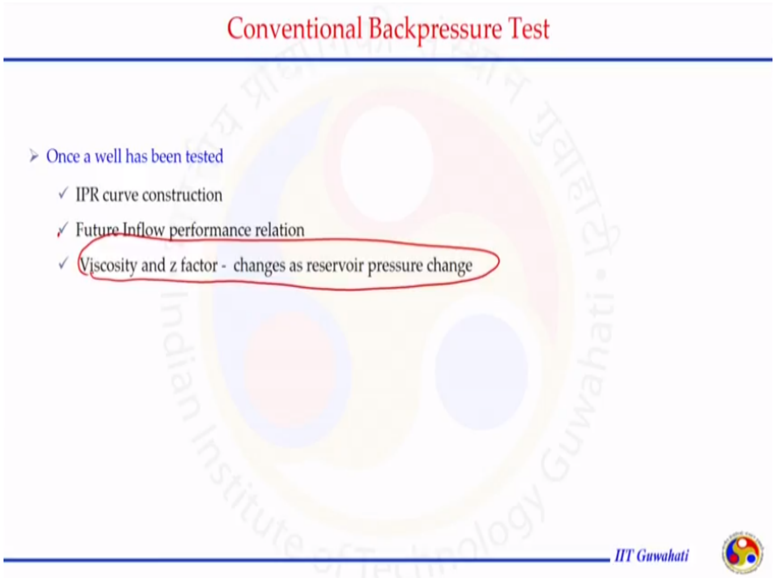

So I think it is clear how to perform the conventional backpressure test. Once a well has been tested we got the value of the co-efficient we got the value of AOF, we can construct the IPR curve, we can future inflow performance relationship can be established and viscosity and z factor need to be changed as the reservoir pressure is changing. This is utmost necessary either you are changing the value of the pressure or the coefficient are adjusted as discussed before.

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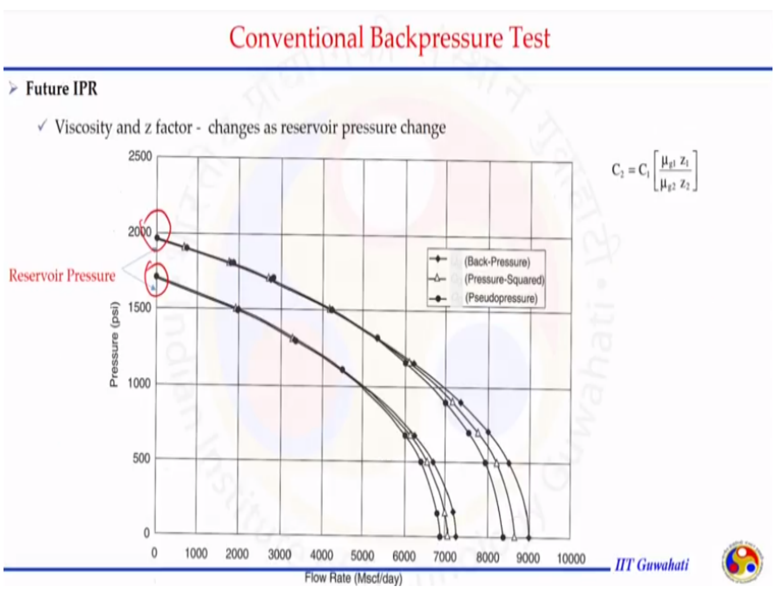

And once we know this thing we can predict the future performance again at any reservoir pressure condition how the flow will happen. And it is important like what is discussed here. In this case we are having the pressure versus Q. Here we are having pressure versus pressure divided by flow rate versus Q relationship and this will give us more accurate with compared to the log data.

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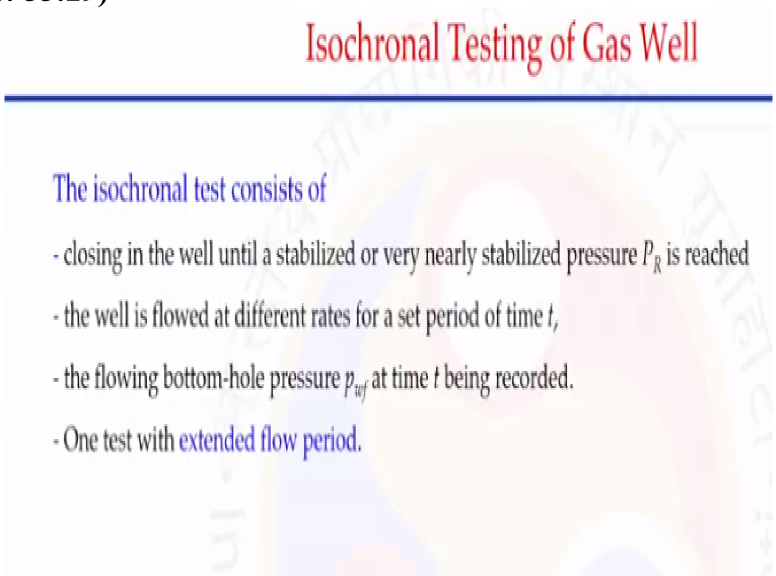

So another important that we already discussed, correct this either mean and the Isochronal test the second class of the gas well testing is Isochronal testing. This Isochronal test consist of closing the well until a stabilized very near stabilized pressure PR is reached. The well is flowed at a different rate for a set period of time T. The flowing bottom hole pressure at time T being recorded. One test with extended flow rate is conducted.

So what exactly we did in a conventional backpressure test we just changed the flow rate, we wait till the pressure is stabilized. So we used the stabilized IPR empirical relationship and that is used when we say the pressure is stabilized.

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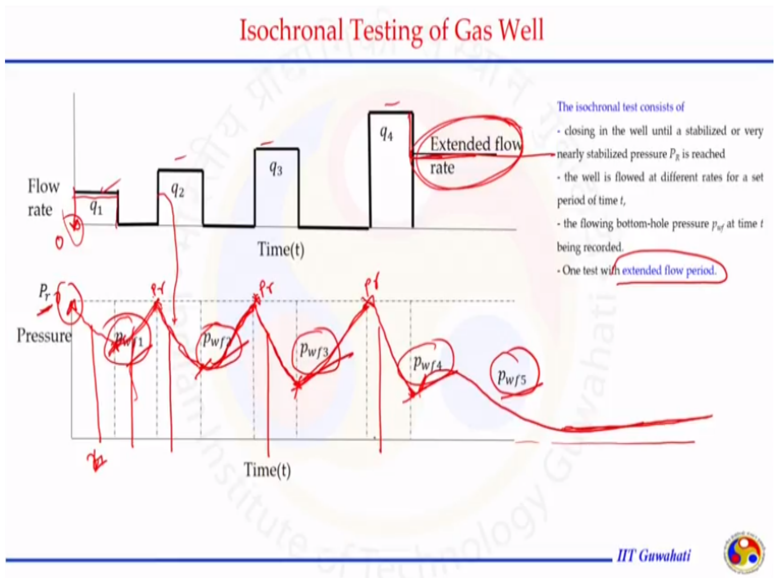

But in this case we are waiting to a condition when the reservoir pressure is established here PR and there is no production here, 00 condition is here. And the well is put under flow rate q1. So when we are putting the well under flow rate it will be like this. And before it is established for a certain time the well is flowed for a constant time q1 it is shut down again.

When we are shutting it down it will go like this and it should shut down till we are reaching again the same pressure value as PR. Once we reach that PR value the well is put again operating condition, this condition and when we are producing the pressure will drop down again and if the flow rate is higher more drop down will happen and in the next case again it is shut down after certain time.

So what will happen, pressure will build up again and we will wait till the pressure again reaching the reservoir pressure PR. And once it is happening again another flow rate is set and we see if the flow rate is higher more drop down will happen; again wait for a longer time because the more drop down happen to reach the PR condition more time is required. Once we reach PR condition here situation will be like this.

Another way it can be done again when we are getting the production with higher flow rate q4. We are reaching here and when it is put in any extended rate for example here. So the pressure will build up because it is time to reduce the flow rate and then when it is a extended flow rate pressure drop down will happen at a constant rate it is flowing like this extended flow rate it is not shut down okay P5, P4, P3, P2, P1 can be established.

So in this test, I will repeat again the well is closed until a stabilized condition is appearing here and when it is established condition it start producing at a constant flow rate for sometime the constant time T, and then put under certain condition for a certain time when the well is returning to PR, the bottom hole pressure is returning to PR condition put the well under a different or second flow rate condition. Let the pressure drop down happen.

Again close the well, when we are closing the well means no production is happening. shutting the well the pressure build up scheme will follow and the pressure will reach again the PR condition. Again similar thing is done when the gas is flowed at a q3, we are reaching here 3 condition, 4 condition, and at the end we are getting this thing.

So what we get from this data set, we are having the time, constant and at that particular time when we are change in the flow rate how much pressure is achieved at a bottom hole condition. And one extended flow rate is done just to make sure how to how truly the gas well will behave when we are having a constant flow rate. Here the flow rate is changing under q1, q2, q3.

q1 is for a certain time then shut in, then q2 establish then shut in again, similar for q3 shut in again, q4 then a constant flow rate. This we are getting the q5 this q5 or Pwf5 at a constant condition. This we call as extended flow condition. So by knowing this data what we can do, we can say at a particular time what exactly is happening and when the reservoir pressure is returning back, how much time is required to returning back. This information can be used to stabilize the IPR curve.

And in that IPR curve let us say, when we say a particular time chosen this is the way the data will be. For example here if I choose particular time, T1 let us say 2 minutes. And every time after 2 minutes when the well is put under certain condition opening condition, I can measure the pressure condition and the flow rate condition.

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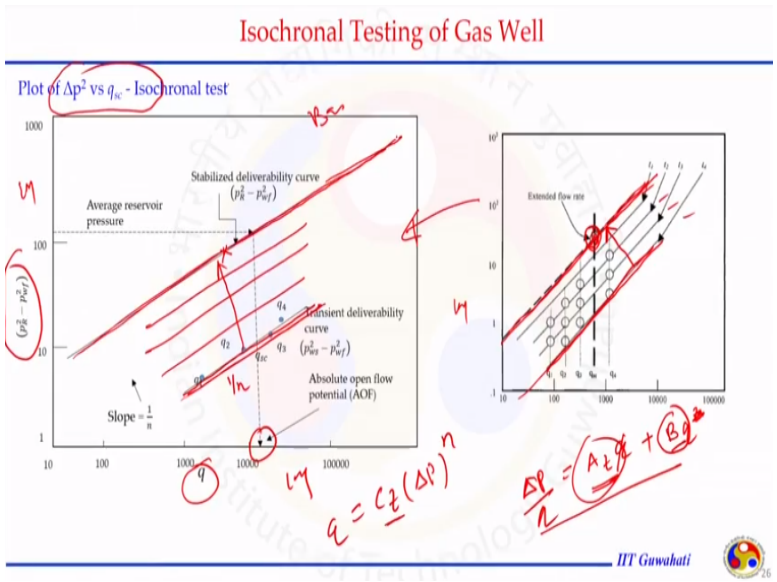

T1 condition is here, T1, T2, T3, T4 they will give me a parallel line. And this is happening you know why because we know under the gas well is under a transient condition. The pressure is not stabilized. The well is under a transient condition. And Under transient condition our equation, quadratic equation is like this. Ayq + Bq square.

So in that case if you see if you fix a particular time, we are measuring the data of the pressure versus q, the B will, the slope will remain the same if we plot like this. This slope will remain the same while the At intersect will change and this is happening exactly if we are plotting on a Cartesian system where this plot is on a log scale. Here del P=Ct del P sorry here q = Ct del P to the power n.

So here only Ct is changing, this slope is changing on the log scale. Here in this case the At will change. Only the slope will change with this time. So we can plot this data at a particular time to just get the slope of the equation and to get the real data that can be the extended flow rate condition and the extended flow rate condition is here. So what we can do, we can just draw the parallel line to it which is passing from this extended flow rate condition. So this is the actual conditions through which the production will happen.

Or when the stabilized condition the flow rate will happen under the Isochronal condition test and once we know this we can estimate the AOF condition that can be understood better by seeing this here del P square versus q Isochronal test has been performed for a backpressure method. And in this thing this is the pressure draw down versus q on a log scale will give this 1/N this slope is here.

And that slope will remain the same does not matter what time we are taking the data. We can take several time also or just one set is good enough and this is the extended flow rate condition. And under the extended flow rate condition we can establish the parallel line here and this will be our stabilized deliverability curve. From this curve we can say what is the average reservoir pressure, what is the AOF Absolute open flow condition can be achieved.

So in a Isochronal testing the difference between the conventional Isochronal testing is in this test we do not need to wait till the pressure is stabilizing in the formation or at the bottom hole condition and we can use the transient curve or transient data at a particular time to stabilize the relationship and that relationship can be extended in a parallel manner to the extended flow condition and from that equation we can get the stabilized deliverability curve that can be used for a IPR correlation development.

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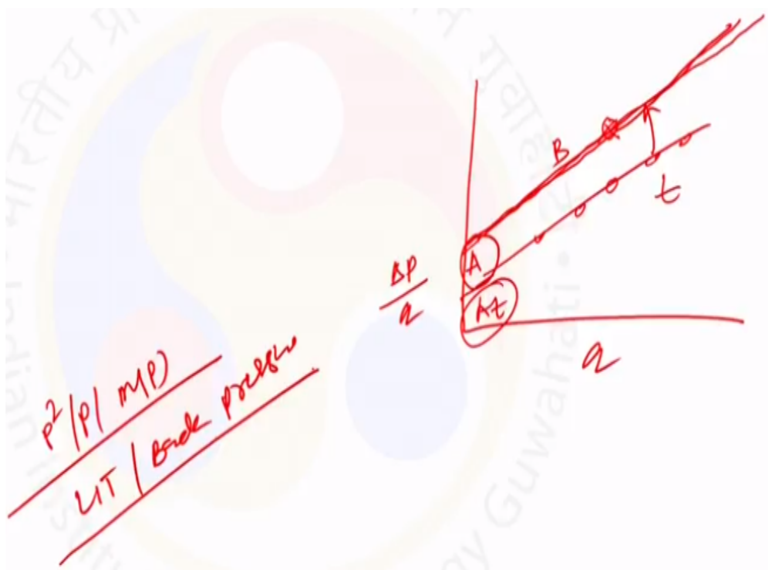

That pressure method it is shown here in the form of p approach, similar can be done on a Cartesian Coordinate system for pressure flow rate divided by q for the different cases of data at a particular time T from which we can get a value for the extended condition. That extended condition says is actual true condition which is parallel to this line and we can get the actual value of this A.

This will give us the At and At will change with the time while the extended data will give us the value of A that has become the constant and slope will give us the value of B. So again this can be done for P square / P / mp approach and under both LIT and backpressure conditions so this is transient based deliverability test.

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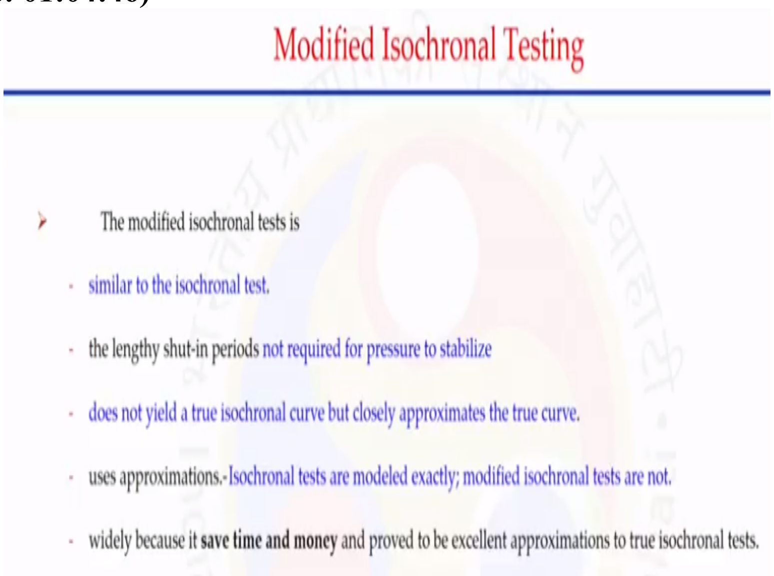

In modified Isochronal test what is this similar to Isochronal test, the length shutting period is not required for the pressure to stabilize. So in the Isochronal test what we were doing? We are flowing at a constant rate and then in the well pressure the built up and we are waiting till the pressure is reaching the reservoir pressure. But in this case, in a Modified Isochronal test we do not need to wait that length is shutting period is not required for the pressure to stabilize does not yield a true Isochronal test but closely approximate the true curve.

Uses approximation like Isochronal test while the modified Isochronal test are not. But it is widely used because it saves time and money because in the case of conventional test or let us say in the case of Isochronal test the gas well is put under the certain condition for a certain time and under that time when it is under the observation just under the certain time we are not producing anything we are wasting the time and money.

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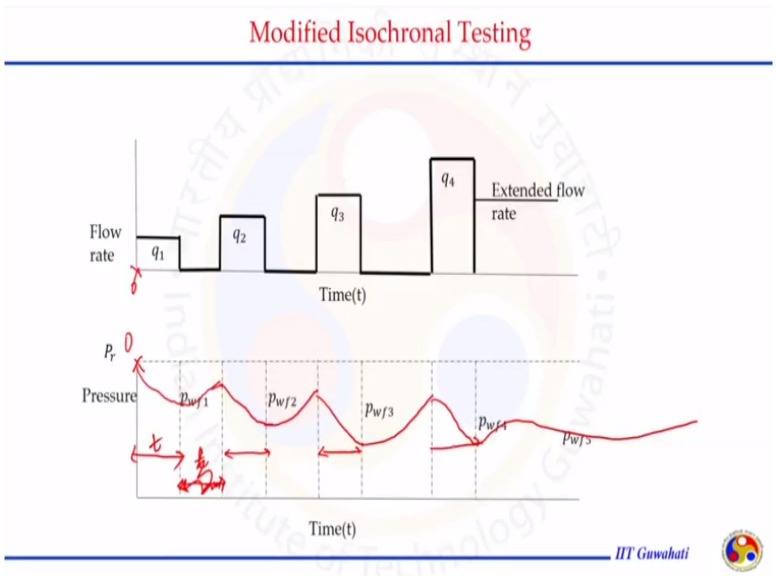

So in this test what we do, similar to the Isochronal test the flow rate is given like this in a q1 so PR condition that is the 0 condition where the reservoir is not producing, it has been established put under a production, what will happen the pressure will decline here okay. And when you shut in the well it will go to improve it. But instead of waiting it is going to base line, the PR line we will start producing at a different flow rate is drop down will happen.

Again shut in period the pressure will build up, q3 pressure will go down, again shut in period pressure will go up, production pressure will go down and again this is like this curve. So in this case the major difference is we are getting the data for a constant time T when we are asking the gas well to produce and the shut in time is different. We can choose shut in time in a different manner.

But the gas well is put under a production conditions, like this is the production condition here, not this one. This is the production condition when the well is put under a constant time and we can get the data for that. Using this data again we can get under different flow rate what was the relationship between pressure difference versus q on a log scale in backpressure method, we can get this curve and this curve is again depend on the time we are choosing.

This slope will be similar to what is for the extended flow condition. But extended flow condition like the chronicle method will give us the point and that point will allow us to establish the IPR curve. So other things are similar to what is for the Isochronal test. The only advantage in this method is we are reducing the time of gas well testing.

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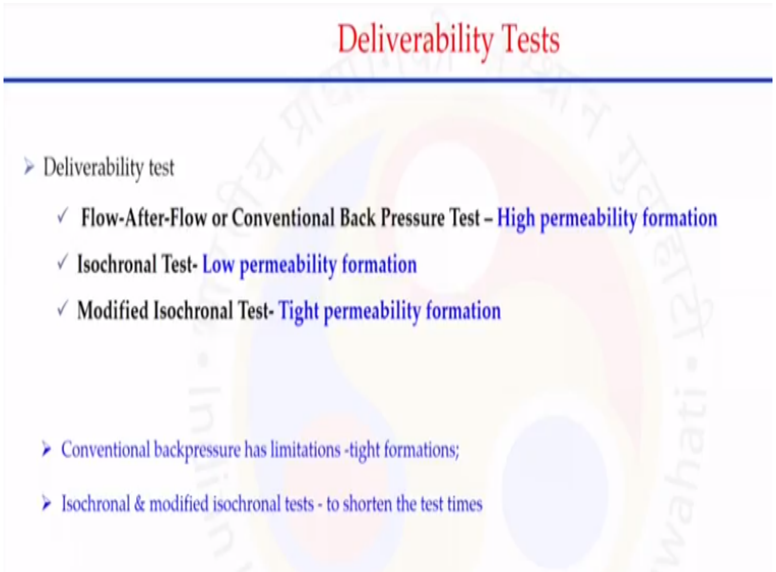

So in summary deliverability test flow-after-flow or conventional back pressure test or simpler test those are operated under the stabilized conditions and the high permeability formation reservoir reach stabilized condition in a lesser time. So these tests should be performed when the reservoir is having the high permeability formation.

Isochronal test is low permeability formation because it needs some time to reach Pwf to PR condition while if the reservoir formation is very tight we cannot spend that much time when the pressure is reaching to, Pwf is reaching to PR or when the pressure is stabilizing we should go with the modified Isochronal test. Conventional pressure has limitation is tight formation it cannot be used while the Isochronal and modified Isochronal test they reduce the time and they save the money while performing the test. thank you, thank you very much for listening the lecture.