Advanced Reservoir Engineering

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Chapter 3 Water Drive Curve Analysis

Water drive curve analysis is a very common method in oilfield . Its main application is to seek for recoverable reserves (N_R) , recovery factor (E_R) and many useful information for oilfield development, which is an important method in reservoir engineering.

For water drive oilfield, when it comes to development and enter into a stable production stage, if we plot the cumulative water production (W_p) and cumulative oil production (N_p) , or water-oil ratio (WOR) and cumulative oil production (N_p) separately on semilog coordinate paper, after the water-cut (f_W) to a certain height and gradually rise, often have a straight line, this kind of curve is called the water drive curve.

Main Aplication of Water Drive Curve

1. Determine the water flooding reserves (N)
2. Determine the water flooding recoverable reserves (N_R)
3. Determine the oil recovery factor (E_R)
4. Predict the water-cut (f_w)
5. Predict average water saturation of formation (S_w)
6. Seek for the K_{ro}/K_{rw} with oilfield production data
7. Predict future oilfield production

Chapter 3 Water Drive Curve Analysis

Section 1 Four types of water drive curve

Section 2 Type A water drive curve

Section 3 Correction method of water drive curve

Section 4 Oil well performance law

Section 1 Four types of water drive curve

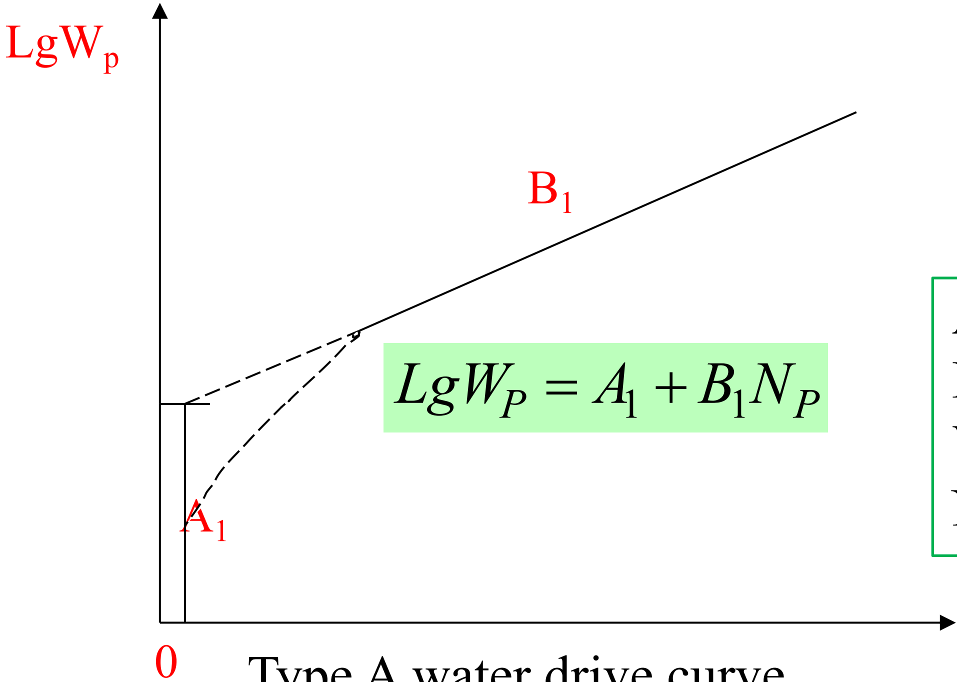
Although there are many water drive curves, we often use A, B, C, D four types water drive curves, which has a very practical application value.

1.Type A Water Drive Curve

Type A water drive curve refers to the cumulative oil production (N_p) and cumulative water production (W_p) of semilog straight-line relation, the basic formula is:

$$LgW_P = A_1 + B_1 N_P$$

It was come up with by the former Soviet union scholar Maximov in 1959 as empirical formula:



Type A water drive curve

$$LgW_P = A_1 + B_1 N_P$$

A_1——intercept
B_1——slope
W_p——cumulative water production
N_p——cumulative oil production

$$A_1 = Lg\frac{2N\mu_o B_o \rho_w}{3mn\mu_w B_w \rho_o (1 - S_{wi})} + \frac{m(3S_{wi} + S_{or} - 1)}{4.606}$$

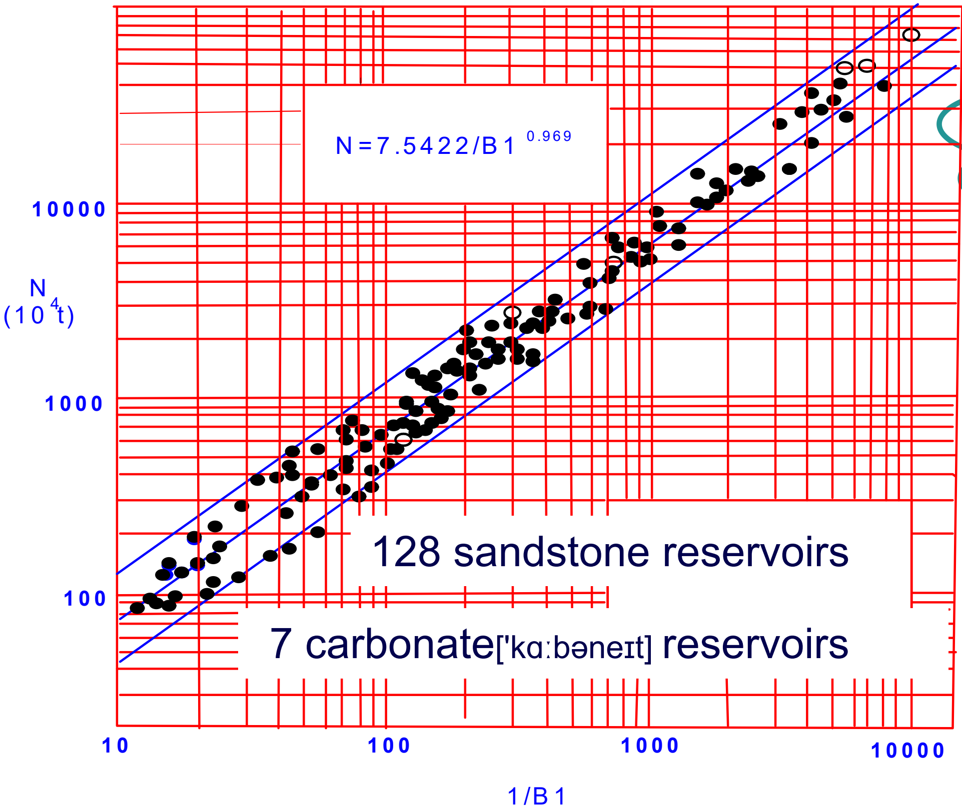
$$B_1 = \frac{3mS_{oi}}{4.606N}$$

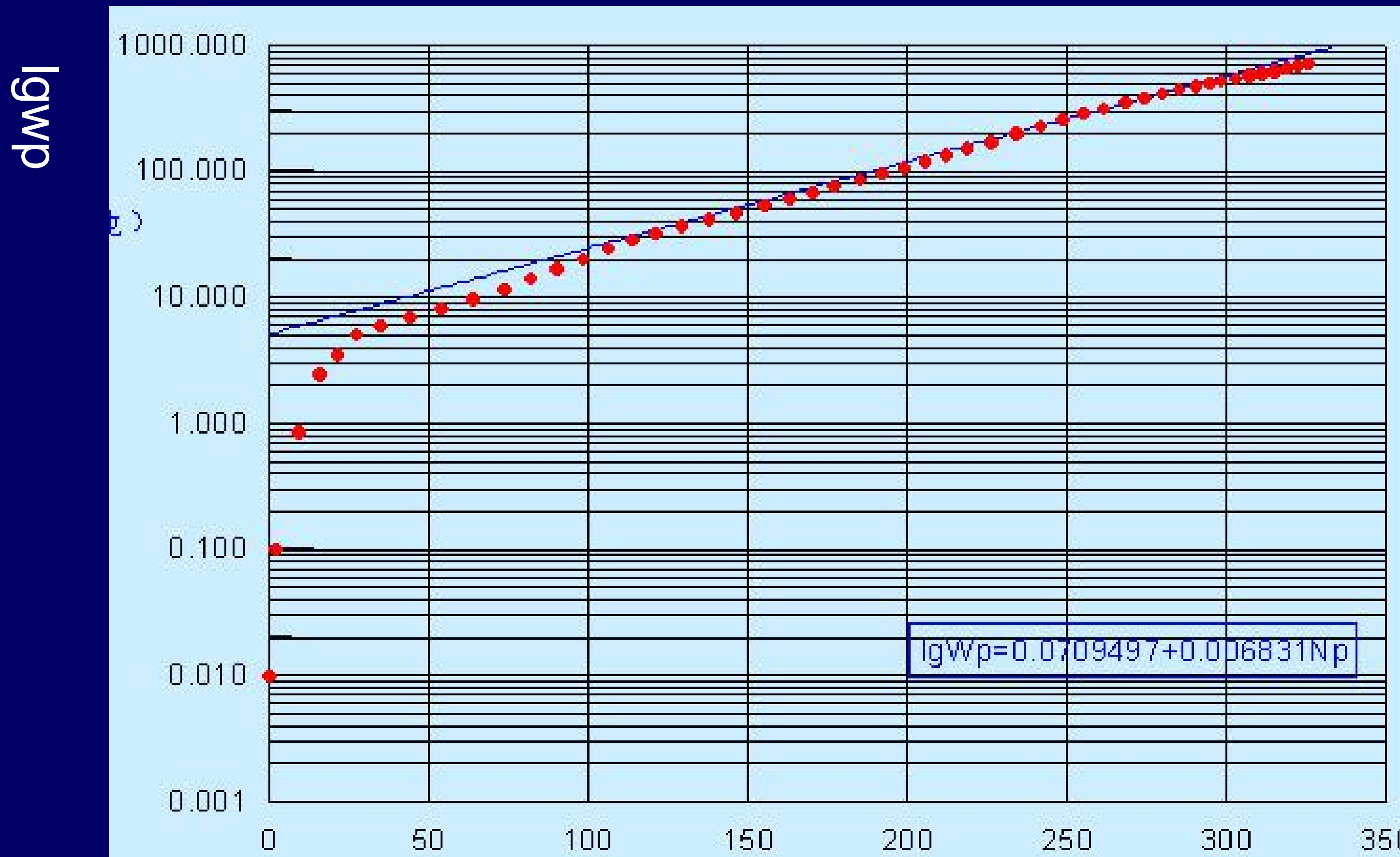
The relation of B_1 and N

- Tong Xianzhang: $N = 7.5 / B1$
- Chen Yuanqian correction formula: $N = 7.5422 / B_1^{0.969}$

This is the former formula, relatively simple

Now in the oilfield use this formula is more, because it is more accurate





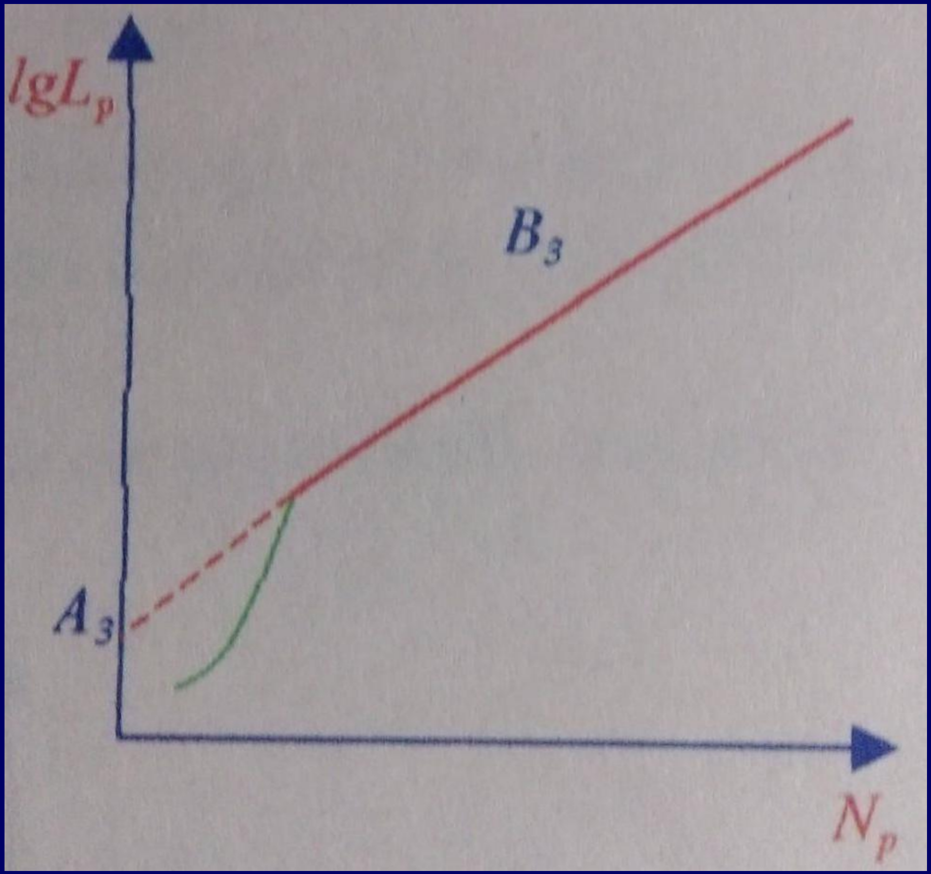
Type A water drive curve

Np

2.Type B water drive curve

Type B water drive curve refers to the cumulative oil production (N_p) and cumulative liquid production (L_p) of semilog straight-line relation,the basic relation formula is:

$$LgL_p = A_2 + B_2 N_p$$

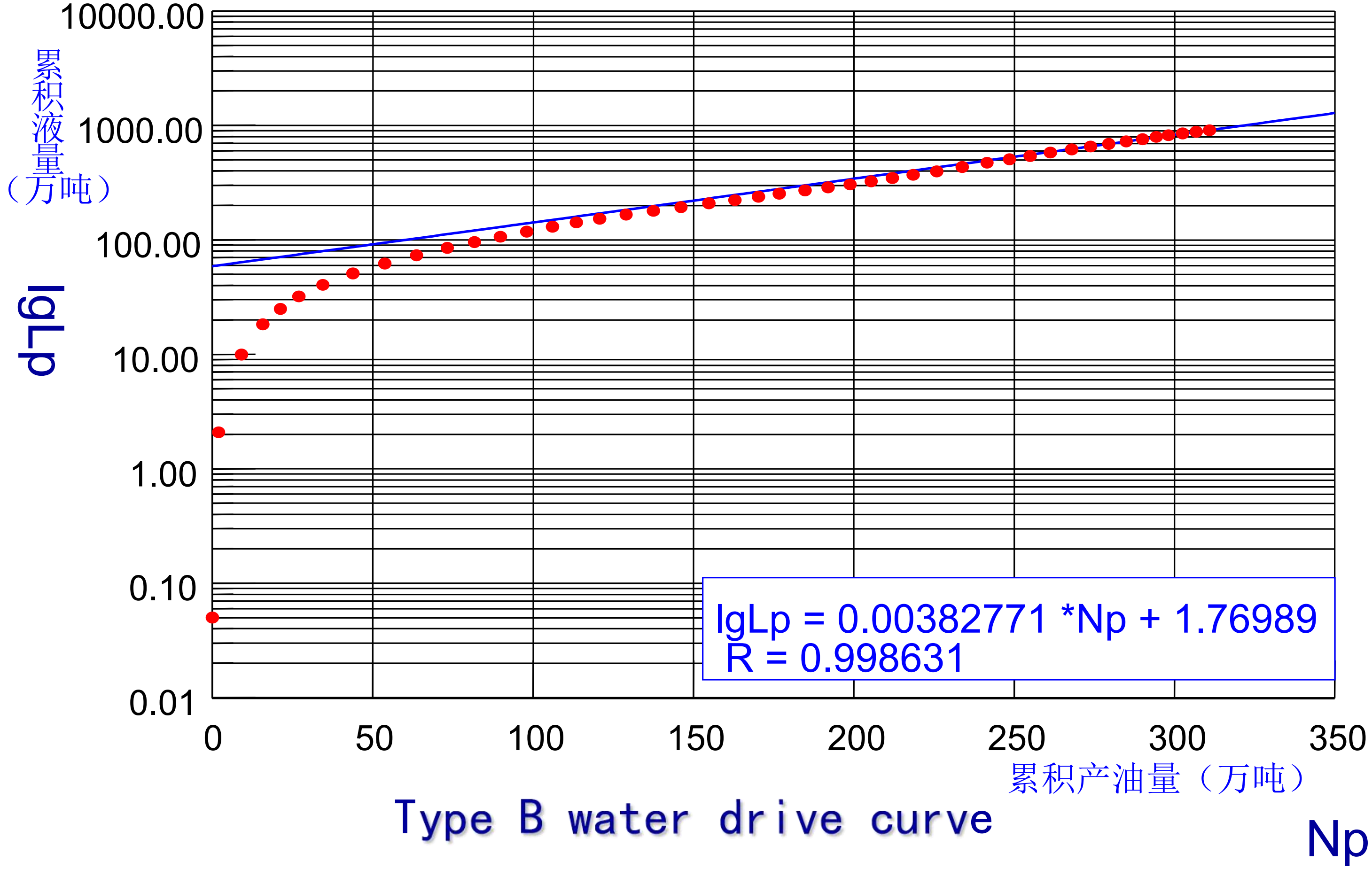


$$LgL_p = A_2 + B_2 N_p$$

Relationship between cumulative oil production (N_p) and water-cut (f_W) :

$$Np = \frac{1}{B}\left\{\lg\left[\frac{0.4343}{B}\left(\frac{1}{1-Fw}\right)\right] - A\right\}$$

If the oilfield economic limit water-cut $(f_w)_{max}$=98%, then we can have the $N_R=(N_p)_{max}$



Type B water drive curve

R is correlation coefficient, the closer to 1, the more relevant

3.Type C water drive curve

Type C water drive curve refers to the cumulative liquid-oil ratio (L_p/N_p) and cumulative liquid production (L_p) is linear relationship,the basic equation is as follows：

$$L_p / N_p = A_3 + B_3 L_p$$

Relationship between cumulative oil production (N_p) and water-cut (f_W) :

$$N_p = \frac{1 - \sqrt{A_3(1 - f_w)}}{B_3}$$

If the oilfield economic limit water-cut $(f_w)_{max}$=98%, then we can have the $N_R=(N_p)_{max}$

Prediction formula of recoverable reserves:

$$N_R = \frac{1 - \sqrt{A_3\left[1 - (f_w)_{max}\right]}}{B_3}$$

Type C water drive curve

4.Type D water drive curve

Type D water drive curve refers to the cumulative liquid-oil ratio (L_p/N_p) and cumulative water production (W_p) is linear relationship,the basic relation formula is:

$$L_p / N_p = A_4 + B_4 W_p$$

1. **Type A Water Drive Curve** $$LgW_P = A_1 + B_1 N_P$$
2. **Type B Water Drive Curve** $$LgL_p = A_2 + B_2 N_p$$
3. **Type C Water Drive Curve** $$L_p / N_p = A_3 + B_3 L_p$$
4. **Type D Water Drive Curve** $$L_p / N_p = A_4 + B_4 W_p$$

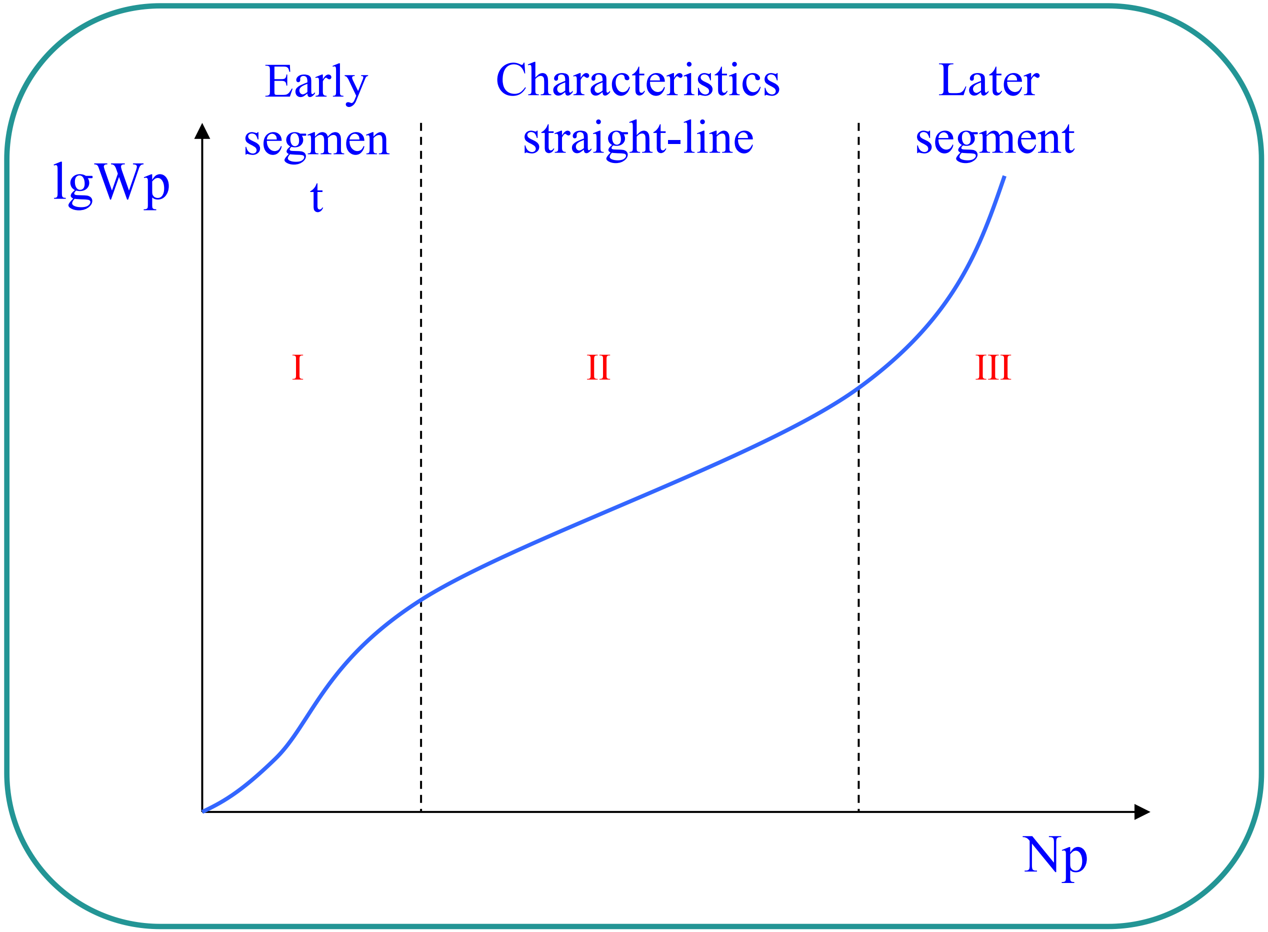
In these four types of water drive curve, the most common method is the Type A water drive curve.So we will focus on the Type A water drive curve

Chapter 3 Water Drive Curve Analysis

Section 2 Type A water drive curve

1. Three section water drive curve
2. The meaning of A_1 and B_1
3. Applicability condition of water drive curve
4. The starting point of straight line
5. Application

1.Three section water drive curve



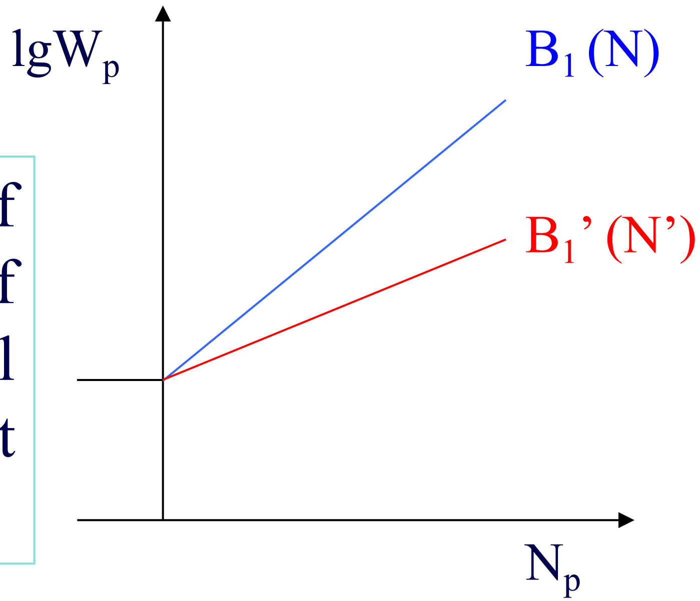
2.The meaning of A_1 and B_1

$$LgW_P = A_1 + B_1 N_P$$

(1)Slope B_1 (if A_1=constant)

$$N = 7.5/B_1$$

N is inversely proportional to B_1 ,if $B_1' < B_1$, then N'>N , with the decrease of the slope B_1, the dynamic geological reserve increases, and the oil displacement effect is obvious.



(2) Intercept A_1 (if B_1=constant)

According to the definition of the water-oil ratio:

$$WOR = \frac{Q_w}{Q_o} = \frac{K_{rw}\rho_w / \mu_w B_w}{K_{ro}\rho_o / \mu_o B_o} \qquad (1)$$

Log on both sides: $$LgWOR = Lg\frac{\mu_o B_o \rho_w}{\mu_w B_w \rho_o} + Lg\frac{K_{rw}}{K_{ro}} \qquad (2)$$

$$LgWOR = A_2 + B_2 N_p = (A_1 + Lg2.303B_1) + B_1 N_p \qquad (3)$$

(2) = (3):

$$Lg\frac{\mu_o B_o \rho_w}{\mu_w B_w \rho_o} + Lg\frac{K_{rw}}{K_{ro}} = (A_1 + Lg2.303B_1) + B_1 N_p$$

$$Lg\frac{\mu_o B_o \rho_w}{\mu_w B_w \rho_o} + Lg\frac{K_{rw}}{K_{ro}} = (A_1 + Lg2.303B_1) + B_1 N_p$$

$$A_1 = Lg\frac{K_{rw}}{K_{ro}} + Lg\frac{\mu_o}{\mu_w} + (Lg\frac{\rho_w B_o}{\rho_o B_w} - B_1 N_p - Lg2.303B_1)$$

constant

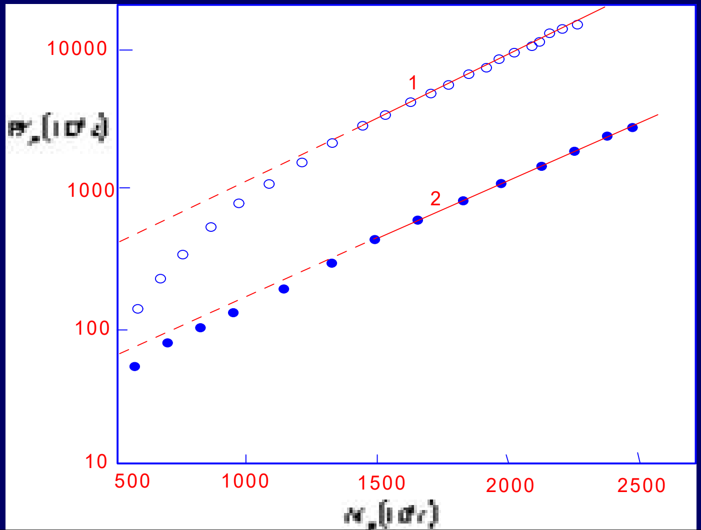
A_1 is mainly affected by K_{rw}/K_{ro} and μ_w/μ_o

From the above discussion, we can come to the conclusion:

Value-A_1 depends mainly on geological reserves and oil-water viscosity ratio.

Value-B_1 is mainly determined by the geological reserves .

For the same geological reserves , If the slope of the straight line is the same, the large oil-water viscosity ratio, has a larger intercept.



3. Applicability condition of water drive curve

(1) The oilfield has to be water flooding developed

(2) The oil reservoir has been into stable production stage

(3) The water-cut has reached a certain stage and been gradually increased

(4) It has to be drawn in the semilog coordinate

4.The starting point of straight line

The starting point of the straight line is very important, If the starting point is wrong, you will get the error of the slope, which leads to the result error.

Oilfield experience has shown that water-cut (fw) greater or equal to 50%, the straight-line will appear.

The principle of selecting straight line

Data points

Good correlation

Conversion relationship between WOR and fw

$$f_w = \frac{Q_w}{Q_w + Q_o}$$

$$WOR = \frac{Q_w}{Q_o}$$

So:

$$WOR = \frac{f_w}{(1 - f_w)}$$

Or

$$f_w = \frac{WOR}{1 + WOR}$$

if f_w=50%, WOR=0.5/（1-0.5）=1

5. Application of type A water drive curve

Workflow

Obtain production data

↓

Plot lgWp ~Np curve

↓

Choose characteristic straight-line

↓

List linear regression equation

↓

Calculate the dynamic development index

Application

With the regression equation of the curve, we could predict the oilfields' geological reserves (N), recoverable reserves (N_R) , recovery (E_R), water-cut (f_w) and average formation water saturation (S_w) , etc.

(1) Predict the water flooding reserves (N)

Empirical formula

Tong Xianzhang: $N = 7.5 / B_1$

Chen Yuanqian Correction formula: $N = 7.5422 / B_1^{0.969}$

(2) Calculate the recoverable reserves (N_R) and oil recovery (E_R)

$$N_R = \frac{\lg(WOR)_{max} - (A_1 + Lg\,2.303\,B_1)}{B_1}$$

$$E_R = \frac{\lg(WOR)_{max} - (A_1 + Lg\,2.303\,B_1)}{B_1 N}$$

In general oilfield, the economic limit water-cut is 98%, fw=98%, so $(WOR)_{max}=49$, $\lg(WOR)_{max} = \lg 49 = 1.6902$

But in the low permeability oilfield, the economic limit water-cut is 95%, fw=95%, so $(WOR)_{max}=19$, $\lg(WOR)_{max}=\lg 19=1.2788$

(3) Predict the water-cut (fw)

$$LgW_P = A_1 + B_1 N_P$$

Time derivative

$$\frac{1}{2.303W_p}\frac{dW_p}{dt} = B_1\frac{dN_p}{dt}$$

Where :

$$dW_p / dt = Q_w$$

$$dN_p / dt = Q_o$$

$$Q_w / Q_o = WOR$$

$$WOR = 2.303 B_1 W_p$$

Because：

$$f_w = \frac{WOR}{(1 + WOR)}$$

$$f_w = \frac{1}{1 + \dfrac{1}{2.303 B_1 10^{A1 + B1Np}}}$$

(4) Predict formation average water saturation (S_w)

The formation average water saturation and cumulative oil production have the following relations:

$$\overline{S}_w = S_{wi} + \frac{S_{oi}}{N} N_p$$

While S_w and WOR have the following relations:

$$\overline{S}_w = A_S + B_S LgWOR$$

Where:

$$A_S = S_{wi} - \frac{S_{oi}}{B_1 N}\left(A_1 + LgB_1 + 0.3623\right)$$

$$B_S = \frac{S_{oi}}{B_1 N}$$

(5) Calculate K_{ro}/K_{rw} with oilfield production data

$$\because f_w = \frac{WOR}{1+WOR} \qquad f_w = \frac{1}{1+\frac{K_{ro}}{K_{rw}}\cdot\frac{\mu_w}{\mu_o}}$$

$$\therefore \frac{1}{1+\frac{K_{ro}}{K_{rw}}\cdot\frac{\mu_w}{\mu_o}} = \frac{WOR}{1+WOR}$$

$$\frac{K_{ro}}{K_{rw}} = \frac{1}{WOR}\cdot\frac{\mu_o}{\mu_w}$$

$$WOR = 2.303 B_1 W_p$$

Example

1.Prediction of Ninghai oilfield by Chen Yuanqian

Four types of water drive curve were used to predicted the recoverable reserve of Ninghai oilfield by Chen Yuanqian.

Prediction results

Type	Correlation coefficient	Recoverable reserve
Type A water drive curve	0.9987	655
Type B water drive curve	0.9973	734
Type C water drive curve	0.9997	578
Type D water drive curve	0.9988	513

2. Prediction of Da Qing and Cheng Bei oilfield by Yu Qitai

Yu Qitai uses four types of water drive curve to predict the reservoirs, the results are as follow:

Prediction results

Type	Da Qing oilfield		Cheng Bei oilfield	
	Correlation coefficient	Recoverable reserve	Correlation coefficient	Recoverable reserve
Type A water drive curve	0.9995	4213.7	0.9997	823.3
Type B water drive curve	0.9998	4612.8	0.9998	869.8
Type C water drive curve	0.9999	3730.4	0.9998	731.0
Type D water drive curve	0.9998	3427.1	0.9996	634.4

Chapter 3 Water Drive Curve Analysis

Section 3 Correction method of water drive curve

1. Correction significance

2. Correction method

3. Estimationof recoverable reserves and recovery

1.Correction significance

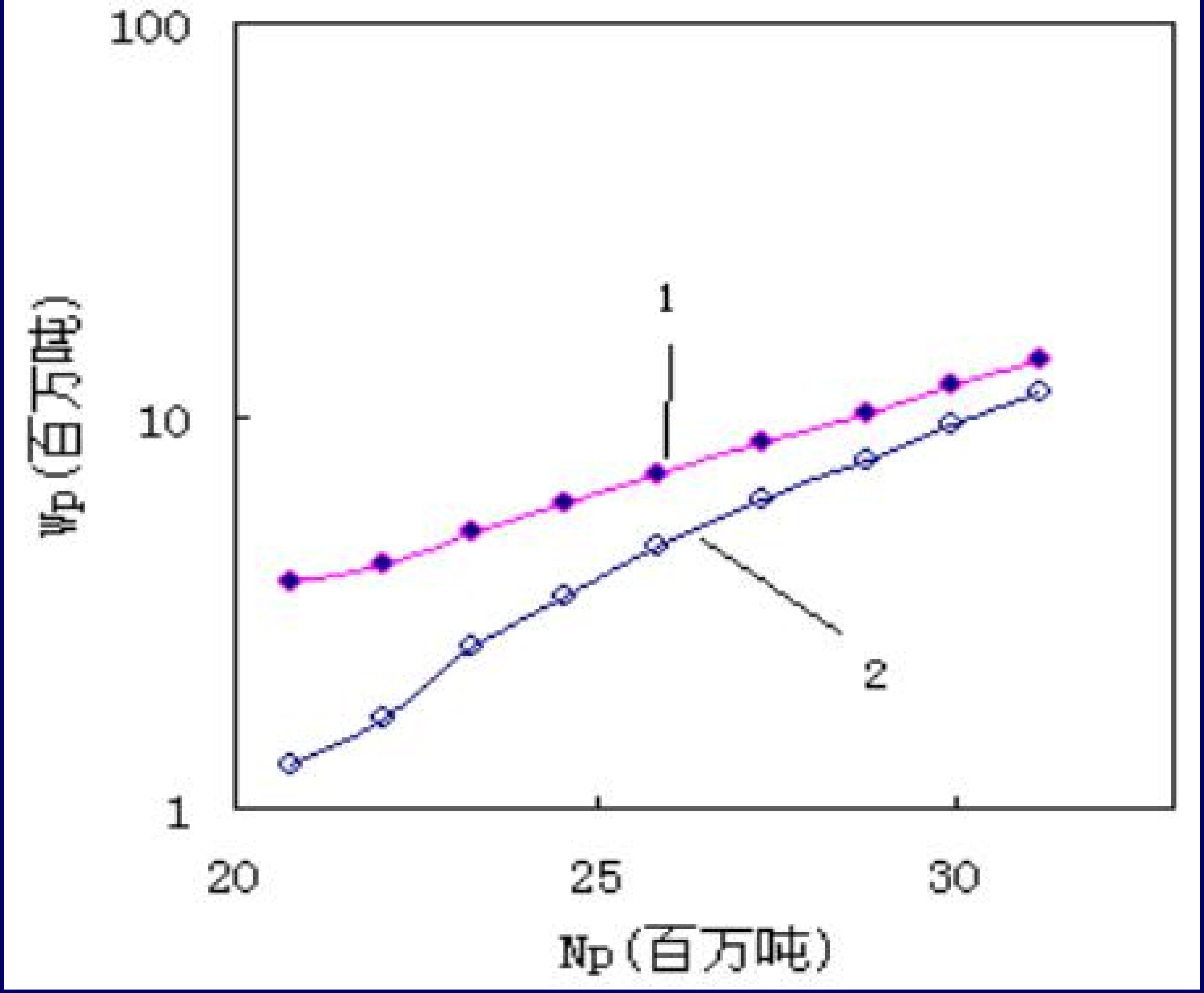
Oilfield experience has shown that water-cut (fw) greater or equal to 50%, the water drive curve's straight-line will appear.

In the early stage, it is a curve, in order to expand the application, it is necessary to correct the water drive curve.

$$Lg\left(W_p + C\right) = A_1 + B_1 N_p$$

When enter the stage of oilfield development, after the water-cut reached 50%, and the value- W_p is larger, the effect of constant C is ignore.

Therefore, if you want to use water drive curve to solve the problem in the early stage, it is necessary to determine the constant C.



1—Corrected water drive curve；2—Water drive curve

2. Correction method

(1) Using early production data to calculate C value

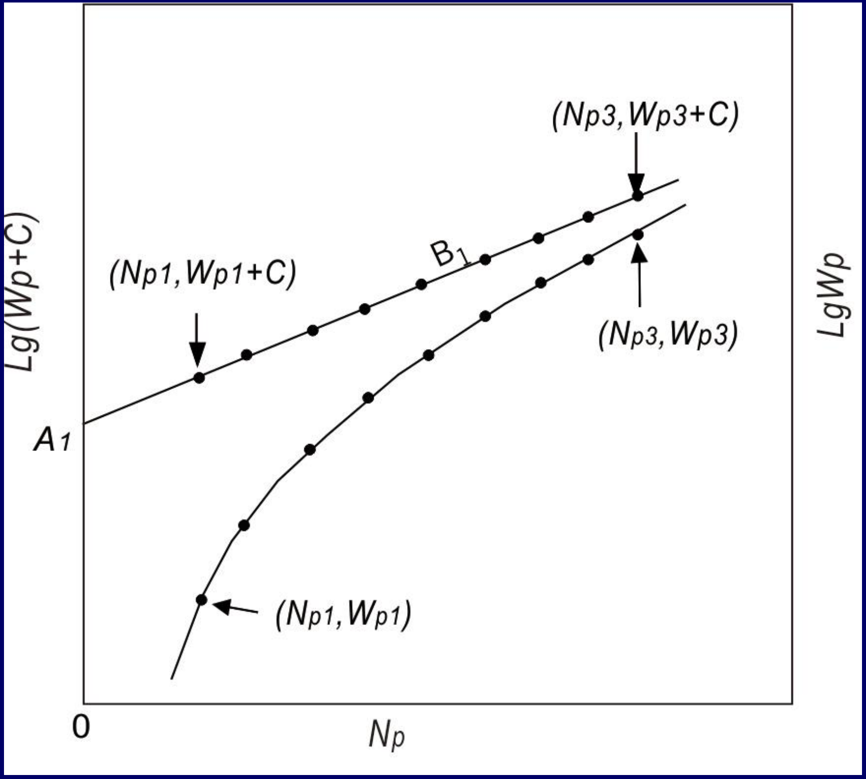
(2) Curve shift method

(3) Using the relationship between water-oil ratio and cumulative oil production to determine C value

(1) Using early production data to calculate C value

Step-1. Draw type A water drive curve of $\lg W_p$ vs. N_p, based on the actual production data

Step-2. Two points at the head and tail of type A water drive curve are taken， the abscissa is respectively N_{p1} and N_{p3}， W_{p1} and W_{p3} as the ordinate, N_{p2} can be calculated by the following formula：



$$N_{p2} = \frac{1}{2}(N_{P1} + N_{P3})$$

Step-3. Based on the N_{p2} value, the corresponding W_{p2} value can be obtained on the type A water drive curve, so, on the straight line of the corrected water drive curve, by using the three points of data, the constant C is obtained by the method of calculating the slope of the straight line

$$\frac{\lg(W_{p3}+C)-\lg(W_{p1}+C)}{N_{p3}-N_{p1}}=\frac{\lg(W_{p2}+C)-\lg(W_{P1}+C)}{N_{p2}-N_{p1}}$$

$$\lg\left(\frac{W_{p3}+C}{W_{p1}+C}\right)=\frac{N_{P3}-N_{P1}}{N_{P2}-N_{P1}}\lg\left(\frac{W_{P2}+C}{W_{P1}+C}\right)$$

$$C=\frac{W_{P1}\times W_{P3}-W_{P2}^{2}}{2W_{P2}-(W_{P1}+W_{P3})}$$

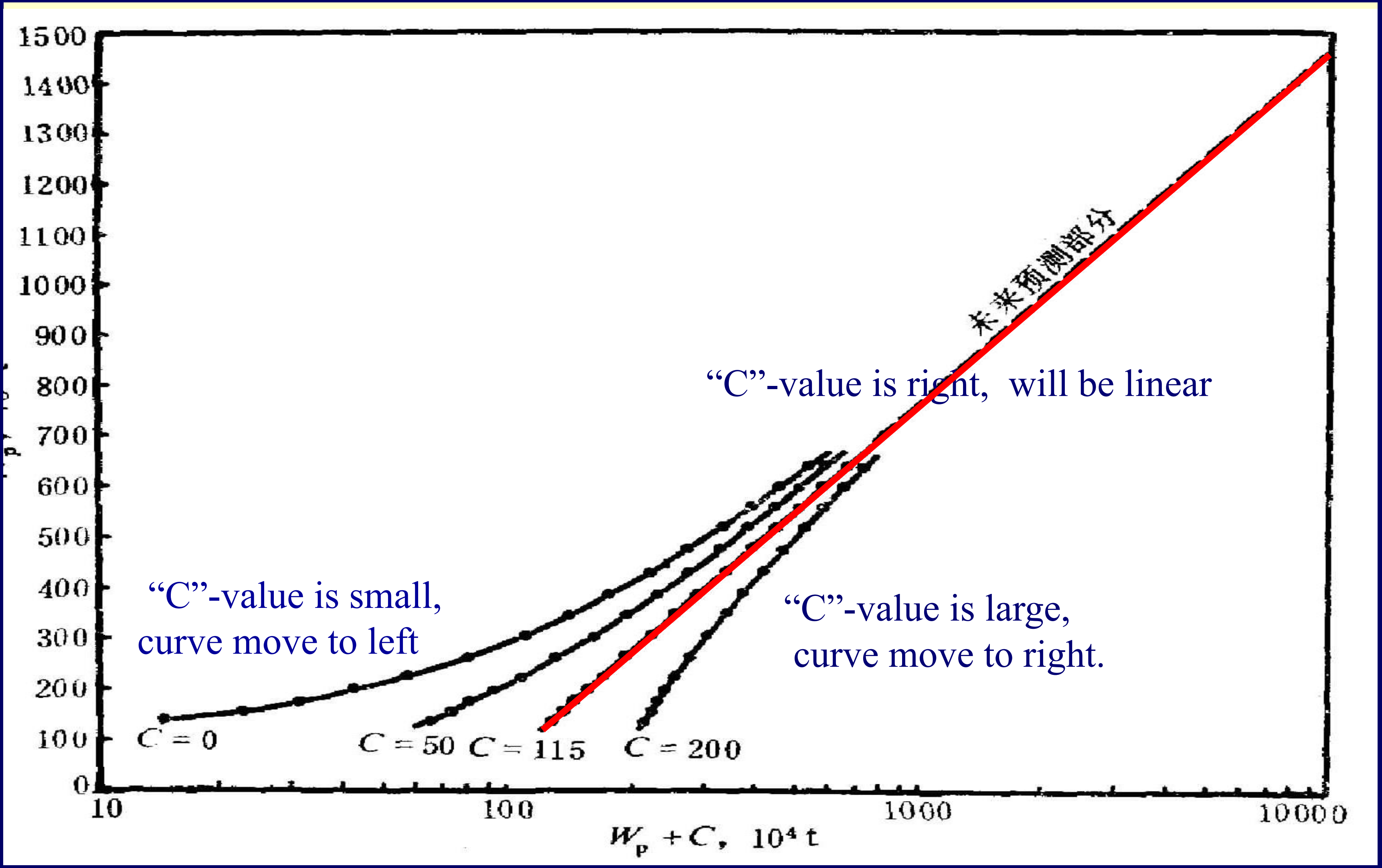
(2) Curve shift method

$$N_p = a + bLg(W_p + C)$$

Where: $a = -A_1/B_1$, $b = 1/B_1$

Given different "C"-value , to calculate the different value of (W_p+C) , if the "C"-value is right, a plot of $N_p \sim lg(W_p+C)$ will be linear , but if the "C"-value is small ,we will have a curve move to left ,whereas , if the "C"-value is large ,we will have a curve move to right.

C—— Curve shift constant



1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
10
100
1000
10000
$W_p + C$, 10^4 t
未来预测部分
"C"-value is right, will be linear
"C"-value is small, curve move to left
"C"-value is large, curve move to right.
C = 0
C = 50
C = 115
C = 200

(3) Using the relationship between water-oil ratio and cumulative oil production to determine C value

Time derivative

$$N_p = a + bLg(W_p + C)$$

$$\frac{dN_p}{dt} = \frac{b}{2.303(W_p + C)}\frac{dW_p}{dt}$$

$$W_p + C = \frac{bWOR}{2.303}$$

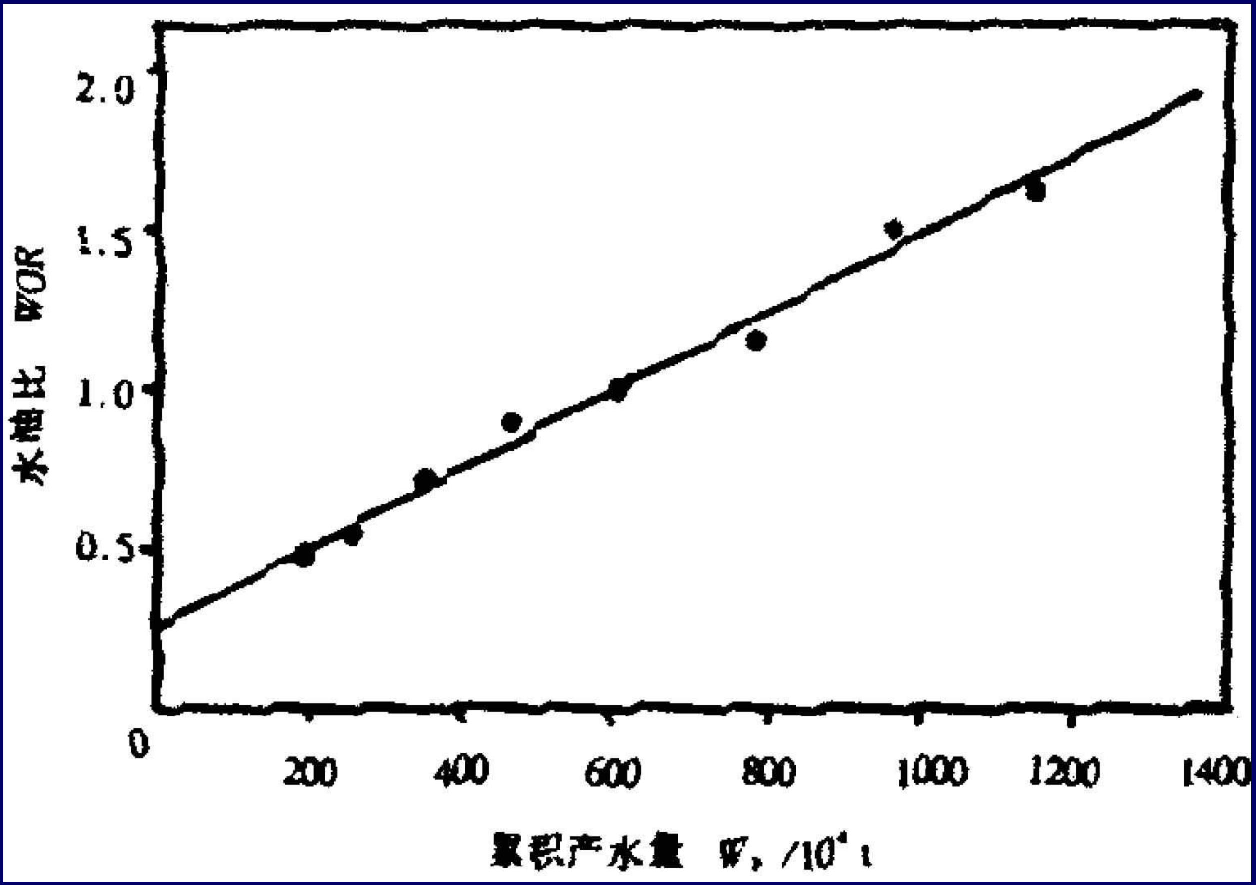
$$WOR = \frac{2.303\,C}{b} + \frac{2.303}{b}W_p$$

$$a' = \frac{2.303\,C}{b}$$

$$WOR = a' + b'W_p$$

$$b' = \frac{2.303}{b}$$

$$C = a'/b'$$



Wp - WOR relationship curve of a water flooding oilfield

Comparison of three correction methods

The first method is influenced by random factors, which is prone to error.

The second method is easy to operate, but needs to do a lot of graphs, easy to miss the best value, In addition trial and error is not easy to determine the initial value.

The third method is simple and applicable, but the method must have a good linear relationship between the water-oil ratio and the cumulative water production.

3. Estimation of recoverable reserves and recovery

$$W_p + C = \frac{bWOR}{2.303}$$

$$N_p = a + b \lg\left(\frac{bWOR}{2.303}\right)$$

$$f_{w\,\max} = 98\%$$

$$(WOR)_{\max} = 49$$

Recoverable reserves

$$N_R = a + b \lg(21.28\, b)$$

$$N = 7.5422\, b^{0.969}$$

Recovery

$$E_R = \frac{0.1326\left[a + b(\lg b + 1.3280)\right]}{b^{0.969}}$$

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Section 4 Oil well performance law

1.Basic concept

2.Oil well performance law

3.To increase the production pressure diffence and liquid yield for stable oilfield production

4. Prediction of liquid recovery rate

1.Basic concept

(1) Oil productivity index (J_o)

(2) Specific oil productivity index (J_s)

(3) Dimensionless oil productivity index (J_D)

(4) Liquid productivity index (J_L)

(5) Bottom hole flowing pressure (P_{wf})

(6) Wellhead pressure (P_o)

(7) Current formation pressure (P)

(8) Hydrostatic pressure

(9) Production pressure difference ΔP

(1) Oil productivity index (J_o)

Oil productivity index commonly used to measure the ability of the well to produce.Defined by the symbol J_o

It 's the ratio of the oil flow rate to the pressure drawdown.

For a water-free oil production, the productivity index is given by:

$$J_o = \frac{Q_o}{P_r - P_{wf}} = \frac{Q_o}{\Delta P}$$

Where：

Q_o =Oil flow rate

J_o = Oil productivity index

p_r =Static pressure

p_{wf} = Bottom-hole flowing pressure

ΔP = Drawdown

(2) Specific oil productivity index (Js)

Since the productivity indices may vary from well to well because of the variation in thickness of the reservoir, it is helpful to normalize the indices by dividing each by the thickness of the well. This is defined as the specific productivity index J_s

It 's the ratio of the oil productivity index to the thickness of the formation .

$$J_s = J_o / h$$

(3) Dimensionless oil productivity index (J_D)

The ratio of the actual oil productivity index to the ideal oil productivity index.

$$J_D = J_{oa} / J_{oI}$$

(4) Liquid productivity index (J_L)

The ratio of liquid production to pressure drawdown

$$J_L = Q_L / \Delta P$$

(5) Bottom-hole flowing pressure (P_{wf})

The pressure measured in the mid-depth of well bottom in the process of production is called well bottom pressure, also known as flow pressure ,with P_{wf} stands for it. It can be expressed by the following formula：

$$P_{wf} = P_o + P_m + P_f$$

Where： P_{wf} —— bottom-hole flowing pressure

P_o —— wellhead pressure

P_m —— Fluid column pressure in wellbore

P_f —— Pressure of fluid loss in wellbore

(6) Wellhead pressure

Wellhead pressure is also known as oil pressure。It is the residual pressure of the oil and gas flow from the bottom to the wellhead.

It can be measured by wellhead oil pressure gauge.Oil pressure can be expressed as follows：

$$P_o = P_{wf} - P_m - P_f$$

Where

P_{wf} —— bottom-hole flowing pressure

P_o —— wellhead pressure

P_m —— Fluid column pressure in wellbore

P_f —— Pressure of fluid loss in wellbore

(7) Initial formation pressure P_i

The reservoir pressure is the fluid pressure within the pores in the middle of oil formation.The reservoirs remain a state of relative equilibrium before development generally,and at this point the fluid pressure is called initial formation pressure.

The original formation pressure of each well is not of equality. Each well should be shut down and test its steady state formation pressure after the first exploration well discovers commercial oil and gas flow ,and pressure should be tested in the beginning of each exploration well , the tested pressure of mid-depth of reservoir is the initial formation pressure of each well.

Strictly speaking , the initial equilibrium is destroyed and the initial formation pressure cannot be obtained any more as long as only once well produces.

If the pressure manometer cannot be put in the mid-depth of reservoir , the initial formation pressure can be calculated from tested pressure gradient .Clearly , in order to improve the measurement accuracy , the pressure manometer should be put in the mid-depth of reservoir as far as possible .

(7) Current formation pressure P

In the process of oil and gas reservoir development , if a well is off production and others are still producing stably , the bottom-hole pressure of the shut-down well will gradually increased.After a long time, the pressure will no longer increase and stabilize. The measured pressure of mid-depth of reservoir of this well is called current formation pressure. And it is also known as static pressure.

(8) Hydrostatic pressure

Hydrostatic column pressure is the water column pressure of the wellhead to the mid-depth of reservoir.

(9) Production pressure difference

Production pressure difference means the difference between the static pressure and flow pressure.

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（1）If oil well water-cut go up, then Jo will go down

According to the famous Dupuit formula,we know:

$$Q = \frac{2\pi k h \Delta p}{\mu \ln \frac{R_e}{R_w}}$$

Where:

Q —— Production rate

h —— Thickness

k —— Permeablity

Δp —— Production pressure difference

μ —— Viscosity

R_e —— Radius of drainage

R_w —— Well radius

Then

$$J_{O(fw=0)} = \frac{Q_o}{\Delta P} = \frac{2\pi h}{\mu \ln \frac{R_e}{R_w}} K_o$$

$$J_{O(fw\neq 0)} = \frac{Q_o}{\Delta P} = \frac{2\pi h}{\mu \ln \frac{R_e}{R_w}} K_1$$

$$\therefore \frac{J_{o(fw\neq 0)}}{J_{o(fw=0)}} = \frac{K_1}{K_o}$$

Where: K_o — — Permeability before water breakthrough

K_1 — — Permeability after water breakthrough

After water breakthrough , there will two phases water and oil , so K_1 less than K_o ,

$$K_1 < K_o$$

$$\therefore \frac{J_{o(fw \neq 0)}}{J_{o(fw = 0)}} < 1$$

$$J_{o(fw \neq 0)} < J_{o(fw = 0)}$$

It means ,after water breakthrough , Jo will go down

（2）If oil well water-cut go up , then oil production rate (Qo) will go down

(If production pressure drowdown is the same)

$$\because Q_{o(fw=0)} = \frac{2\pi h}{\mu \ln \frac{R_e}{R_w}} K_o \Delta P_o$$

$$Q_{o(fw\neq 0)} = \frac{2\pi h}{\mu \ln \frac{R_e}{R_w}} K_1 \Delta P_1$$

$$\therefore \frac{Q_{o(fw\neq 0)}}{Q_{o(fw=0)}} = \frac{K_1}{K_o} \cdot \frac{\Delta P_1}{\Delta P_o}$$

If $\Delta P_1 = \Delta P_0$ then $\frac{Q_{o(fw\neq 0)}}{Q_{o(fw=0)}} = \frac{K_1}{K_o} < 1$

$$\therefore Q_{o(fw\neq 0)} < Q_{o(fw=0)}$$

(3) If oil well water-cut go up , then P_{wf} will increase

$$\because P_{wf} = P_o + P_m + P_f$$

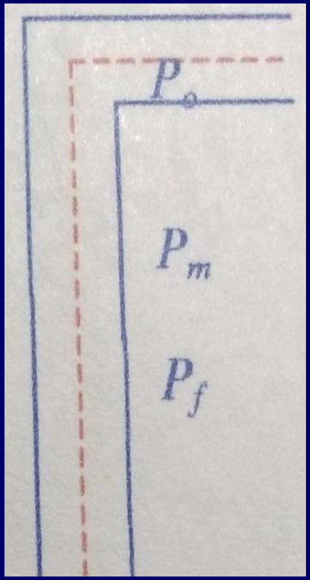
Where :

P_{wf} —— Bottom-hole flowing pressure

P_o —— Well head pressure

P_m —— Liquid column pressure

P_f —— Frictional pressure



$$\therefore P_{wf(fw=0)} = P_o + P_f + P_m = P_o + P_f + \frac{H\gamma_o}{10}$$

$$P_{wf(fw\neq0)} = P_o + P_{f1} + P_m = P_o + P_{f1} + \frac{H\gamma_{ow}}{10}$$

Where : γ_o —— Oil relative density

γ_{ow} —— Oil and water two phases relative density

$$\therefore P_{wf(fw\neq 0)} - P_{wf(fw=0)} = (P_{f1} - P_f) + \frac{H(\gamma_{ow} - \gamma_o)}{10}$$

$$\because (P_{f1} - P_f) = 0$$

$$\therefore P_{wf(fw\neq 0)} - P_{wf(fw=0)} = \frac{H(\gamma_{ow} - \gamma_o)}{10}$$

$$\because \gamma_{ow} > \gamma_o$$

$$\therefore P_{wf(fw\neq 0)} > P_{wf(fw=0)}$$

It means when oil well water-cut go up , then P_{wf} will increase

2.To increase the production pressure diffence and liquid yield for stable oilfield production

(1) Significance

$$\because\ f_w = \frac{Q_w}{Q_w + Q_o} = \frac{Q_L - Q_o}{Q_L}$$

$$\therefore\ Q_o = Q_L\left(1 - f_w\right)$$

In order to stabilize oil production, it is necessary to increase the yield, or reduce the water-cut (f_w) .

But the water flooding oilfield development, with the increase of recovery, it is natural that the water-cut (f_w) keep rising, so after the oilfield into a high water-cut stage, it is necessary to increase the yield.

(2)The production pressure difference can't be enlarged unlimited

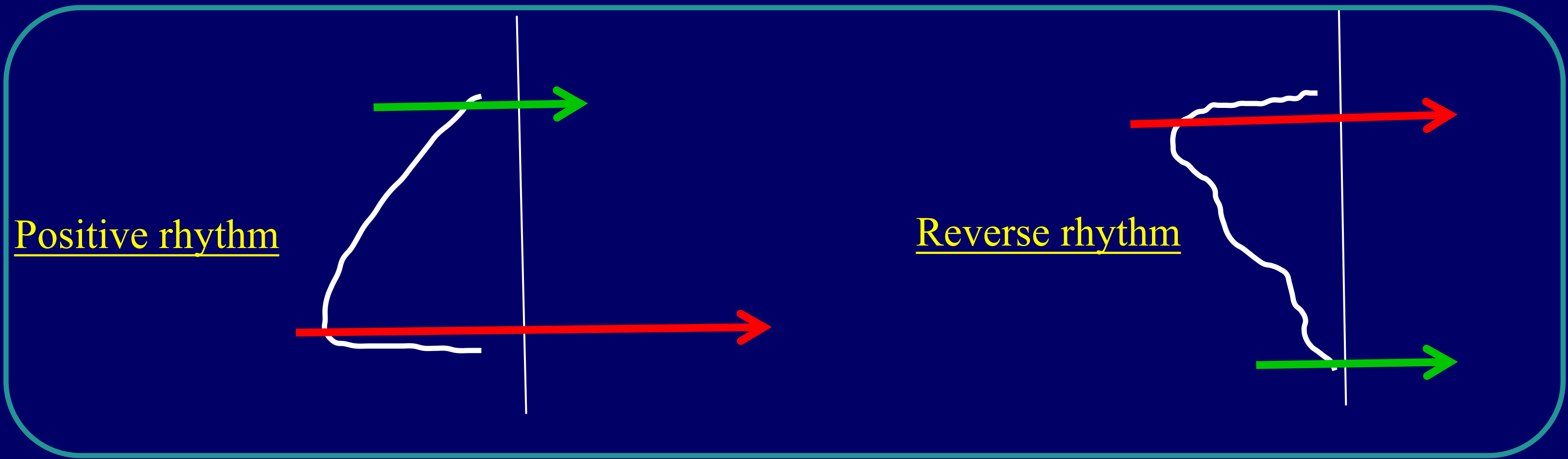
To enlarge the production pressure difference (ΔP), it is generally used to reduce the bottom hole flowing pressure (P_{wf}), but the bottom hole flowing pressure (P_{wf}) can't drop too low.

Too low pressure drop at the bottom of the well will cause side-wall coring and sand production.

When bottom hole flowing pressure (P_{wf}) less than saturation pressure, reservoir degasification near the downhole becomes serious, forming a oil-gas-water three-phase flow, which lower the oil phase permeability, so the oil productivity index (J_o) and the well production capacity both are reduced, the production pressure difference (ΔP) enlarging makes no sense.

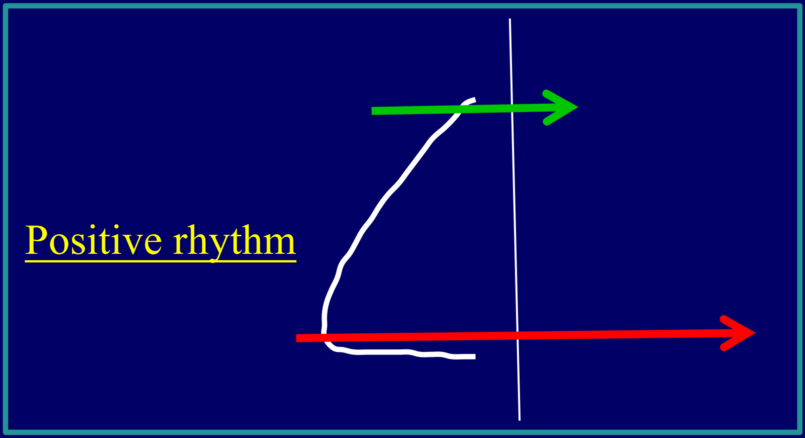
(3) In different sedimentary facies belts, the effect of enlarging the production pressure difference is different

Usually, the effect of enlarging the production pressure difference (ΔP) is better at estuary dam while worse at channel facies

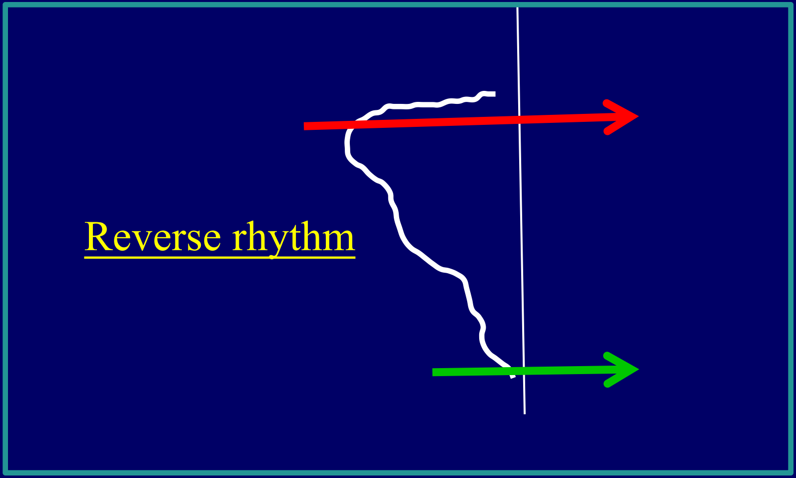


The channel facies is more positive rhythm， the upper part of the permeability is low, the injected water along the high permeability layer; gravity makes water sinking, which makes bigger difference in high-low permeability.

After enlarging the pressure, water along the bottom of the high permeability zone to promote faster, therefore more water, less oil. the effect is bad.



The estuary dam is more reverse rhythm (anti-rhythm)， the injected water by gravity slows down the speed of high permeability， adjust the water, after enlarge the production pressure difference, water advances slow, therefore, the effect is better.



3. Prediction of liquid recovery rate (V_L)

$$V_{oi} = V_{Li}\left(1 - f_{wi}\right)$$

$$V_{Li} = V_{Oi}\left(1 + WOR\right)$$

$$WOR = 10^{a2+b2R}$$

$$V_{Li} = V_{oi}\left(1 + 10^{a2+b2R}\right)$$

$$R_i = R_{i-1} + V_{oi}$$

$$V_{Li} = V_{oi}\left[1 + 10^{a2+b2\left(R_{i-1}+V_{oi}\right)}\right]$$

$$V_{Li} = V_{oi}\left[1 + 10^{a2+b2(R_{i-1}+V_{oi})}\right]$$

Using the above formula, we can predict the liquid production rate , In the stable production stage, V_O is constant, With the recovery percent（R） the previous year, you can work out a reasonable liquid production rate second years.

Meanwhile ,the formula shows that in the stable production stage, to maintain a stable production, the liquid production rate needs to be improved every year.

Example

A productivity test was conducted on a well. The test results indicate that the well is capable of producing at a stabilized flow rate of 110 STB/day and a bottom-hole flowing pressure of 900 psi. After shutting the well for 24 hours, the bottom-hole pressure reached a static value of 1,300 psi. Calculate:

- Oil productivity index
- AOF (absolute open flow)
- Oil flow rate at a bottom-hole flowing pressure of 600 psi
- Wellbore flowing pressure required to produce 250 STB/day

Solution

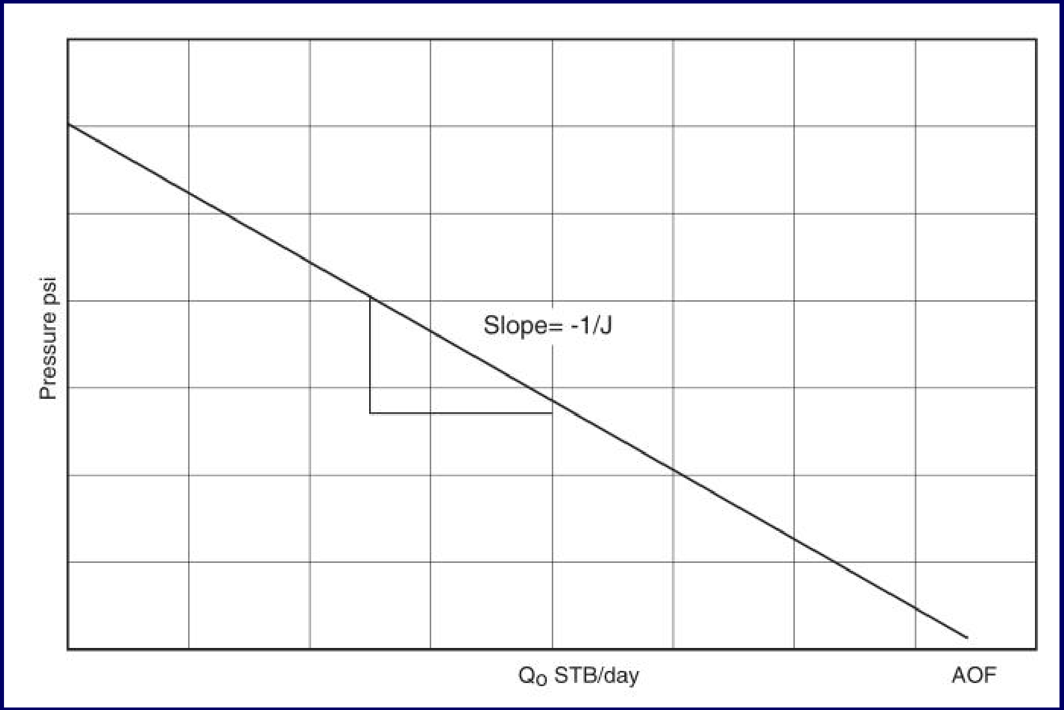
Step-1. Calculate J_o from Equation :

$$J_o = \frac{Q_o}{P_r - P_{wf}} = \frac{Q_o}{\Delta P} \quad \longrightarrow \quad J = \frac{110}{1300-900} = 0.275 \text{ STB/psi}$$

Step-2. Determine the AOF from:

Maximum rate of flow occurs when P_{wf} is zero. This maximum rate is called absolute open flow and referred to as AOF. Although in practice this may not be a condition at which the well can produce, it is a useful definition that has widespread applications in the petroleum industry (e.g., comparing flow potential of different wells in the field). The AOF is then calculated by:

$$J_o = \frac{Q_o}{P_r - P_{wf}} = \frac{Q_o}{\Delta P} \quad \longrightarrow \quad Q_o = J_o(P_r - P_{wf}) = J_o \Delta P \quad \longrightarrow \quad AOF = Q_{omax} = J_o(P_r - 0) = J_o P_r$$



IPR

$$AOF = J\ (\bar{p}_r - 0)$$

$$AOF = 0.275\ (1300 - 0) = 375.5\ STB/day$$

Step-3. Solve for the oil flow rate by applying Equation

$$Q_o = J_o(P_r - P_{wf}) = J_o \Delta P$$

$Q_o = 0.275\ (1300 - 600) = 192.5$ STB/day

Step-4. Solve for P_{wf} by using Equation

$$J_o = \frac{Q_o}{P_r - P_{wf}} = \frac{Q_o}{\Delta P}$$

⇓

$$p_{wf} = 1300 - \left(\frac{1}{0.275}\right)250 = 390.9 \text{ psi}$$