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# Water Drive Characteristic Curve Theory of Low Permeability Reservoir

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## Abstract

The so-called water flooding characteristic curve refers to the oilfield water injection (or natural water drive) development process, a relationship between curve cumulative oil production, cumulative water production and accumulation of fluid production. These curves have been widely used for water injection development of dynamic and recoverable reserves forecast. After many years of practical application, summed up the four kinds of water drive characteristic curve, they have a good practical significance. Recoverable reserves are important indicators of field development and also the main basis for planning and design, while the application of water flooding characteristic curve can be predicted oil recoverable reserves. Four kinds of water flooding characteristics discussed above curve are mainly applied in high-permeability oil field, which did not consider starting pressure. In fact we should consider the impact of low permeability oilfield actuating pressure gradient on the water content. Here, we deduce the formulation considering the actuating pressure.

**Key words:** Low permeability; Water flooding; Actuating pressure

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## INTRODUCTION

Four kinds of drive characteristic curves discussed mainly used in high-permeability oil field, which did not consider starting pressure, but we should consider the impact of low permeability oilfield pressure gradient on the water content[1].

In the case of oil-water two-phase one-dimensional steady flow of work, in line with their respective flow pressure gradient has a linear flow rule[2]:

$$v_o = \frac{K_o(S_w)}{\mu_o}\left(\frac{\Delta p}{L} - G_o\right), \quad (1)$$

$$v_w = \frac{K_w(S)}{\mu_w}\left(\frac{\Delta p}{L} - G_w\right). \quad (2)$$

Where: $v_o$ - The oil phase flow velocity, m/s;

$v_w$ - Aqueous phase flow velocity, m/s;

$\frac{\Delta p}{L}$ - Pressure gradient, MPa/m;

$G_w$ - The aqueous phase starting pressure gradient, MPa/m;

$G_o$ - The oil phase starting pressure gradient, MPa/m.

Because the water content was:

$$f_w = \frac{v_w}{v_o + v_w}. \quad (3)$$

The Formulas (1) and (2) into (3), for the corresponding order, and set $G_o$ Negligible, so that $G = G_o$. It is:

$$f_w = \frac{1}{1 + \frac{K_{ro}}{MK_{rw}}\left(1 - \frac{G}{\Delta p / L}\right)}. \quad (4)$$

Where: $K_{ro}$ - The oil relative permeability;

$K_{rw}$ - Water relative permeability;

$M$ - Oil viscosity ratio.

## 1. THE CUMULATIVE OIL PRODUCTION AND CUMULATIVE WATER PRODUCTION RELATIONS

Assuming the existence of low permeability reservoir Petroleum phase starting pressure gradient[3], and the aqueous phase starting pressure gradient does not exist, ignoring capillary force and the oil-water two-phase pressure difference caused by gravity, the water content can be expressed as:

$$f_w = \frac{1}{1+\left[\frac{KK_{ro}\rho_o}{\mu_o B_o}A(\frac{\mathrm{d}p}{\mathrm{d}x}-\frac{\delta p}{\mathrm{d}x})\right]\Big/(\frac{KK_{rw}\rho_w}{\mu_w B_w}A\frac{\mathrm{d}p}{\mathrm{d}x})} = \frac{1}{1+\frac{\mu_w K_{ro} B_w \rho_o}{\mu_o K_{rw} B_o \rho_w}(1-\frac{\delta p/\mathrm{d}x}{\mathrm{d}p/\mathrm{d}x})} \ . \tag{5}$$

Set: $E = 1-\frac{\delta p/\mathrm{d}x}{\mathrm{d}p/\mathrm{d}x}$, $\mathrm{d}p/\mathrm{d}x = M$.

$$W_p = \frac{2N_o\mu_o B_o\rho_w}{3ab\mu_w B_w\rho_o(1-S_{wi})E}(e^{bS_{we}} - e^{bS_{wf}}) . \tag{6}$$

If so:

$$D = \frac{2N_o\mu_o B_o\rho_w}{3ab\mu_w B_w\rho_o(1-S_{wi})}, \tag{7}$$

$$C = De^{bS_{wf}} . \tag{8}$$

then finishing:

$$EW_p + C = De^{bS_{we}} . \tag{9}$$

Finishing:

$$EW_p + C = De^{\left[\frac{3bS_{oi}N_p}{2N_o}+\frac{b}{2}(3S_{wi}+S_{or}-1)\right]}, \tag{10}$$

then make:

$$F = \frac{b}{2}(3S_{wi}+S_{or}-1), \tag{11}$$

then we have:

$$EW_p + C = De^{\left[\frac{3bS_{oi}N_p}{2N_o}+F\right]}. \tag{12}$$

For Formula (12) take common logarithmic formula was:

$$\log(EW_P + C) = \log D + \frac{F}{2.303} + \frac{3mS_{oi}}{4.606N_o}N_P . \tag{13}$$

If so:

$$A_1 = \log D + \frac{F}{2.303}, \tag{14}$$

$$B_1 = \frac{3mS_{oi}}{4.606N_o} . \tag{15}$$

Then we have:

$$\log(EW_p+C) = A_1+B_1N_P . \tag{16}$$

At this point can be considered the starting pressure gradient curve influenza water flooding relationship is:

$$\log(EW_p) = A_1+B_1N_P . \tag{17}$$

If so:

$$\beta_1 = B_1N_o = 3mS_{oi}/4.06 , \tag{18}$$

$$R_o = N_p/N_o , \tag{19}$$

then we have:

$$\log(EW_p) = A_1+B_1R_o . \tag{20}$$

## 2. THE CUMULATIVE OIL PRODUCTION AND ACCUMULATION OF FLUID PRODUCTION RELATIONS

Assuming the existence of low permeability reservoir Petroleum phase starting pressure gradient, and the aqueous phase starting pressure gradient does not exist, ignoring capillary force and the oil-water two-phase pressure difference caused by gravity[4], it can get:

$$Q_l = Q_o + Q_w = Q_o + Q_o\frac{\mu_o B_o\rho_w}{a\mu_w B_w\rho_o E}e^{bS_w} . \tag{21}$$

Cumulative oil production fluid volume known as:

$$L_p = \int_0^t Q_l \mathrm{d}t . \tag{22}$$

The Formula (21) into (22), we get:

$$L_p = (1+\frac{\mu_o B_o\rho_w}{a\mu_w B_w\rho_o E})\int_0^t Q_o e^{bS_{we}}\mathrm{d}t . \tag{23}$$

Can be obtained using the same method:

$$L_p = (1+\frac{\mu_o B_o\rho_w}{a\mu_w B_w\rho_o E})\frac{N_o}{(1-S_{wi})}\frac{2}{3}(e^{bS_{we}} - e^{bS_{wf}}) . \tag{24}$$

If so:

$$D_1 = (1+\frac{\mu_o B_o\rho_w}{a\mu_w B_w\rho_o E})\frac{N_o}{(1-S_{wi})}\frac{2}{3} . \tag{25}$$

$$C_1 = D_1e^{bS_{wf}} . \tag{26}$$

Finishing:

$$L_p+C_1 = D_1e^{bS_{we}} . \tag{27}$$

Then Formula (22) into (27) finishing type:

$$L_p + C_1 = D_1e^{\left[\frac{3bS_{oi}N_p}{2N_o}+\frac{b}{2}(3S_{wi}+S_{or}-1)\right]}. \tag{28}$$

Then make:

$$F_1 = \frac{b}{2}(3S_{wi}+S_{or}-1) . \tag{29}$$

Then we have:

$$L_p + C_1 = D_1e^{\left[\frac{3bS_{oi}N_p}{2N_o}+F_1\right]} . \tag{30}$$

For Formula (30) take common logarithmic formula was:

$$\lg(L_p + C_1) = \lg D_1 + \frac{F_1}{2.303} + \frac{3bS_{oi}}{4.606N_o}N_P . \tag{31}$$

If so:

$$A_2 = \log D_1 + \frac{F_1}{2.303}, \tag{32}$$

$$B_2 = \frac{3bS_{oi}}{4.606N_o} . \tag{33}$$

Can be considered the starting pressure gradient curve *B* waterflood relationship is:

$$\log(L_P+C_1) = A_2+B_2N_P . \tag{34}$$

The same deduced from Formula (34), the accumulation of fluid production must be coupled with an amount to the cumulative oil production in the semi-logarithmic graph paper into a complete linear relationship. With the continuous increase sustainable production fields, moisture content and cumulative water production, the impact of the constant $C$ decreases[5]. Thus, in the oilfield, the development in the late cumulative water production and cumulative oil production in the semi-logarithmic graph paper has a linear relationship. At this time, that is also considered the starting pressure gradient curve $B$ water flooding relationship:

$$\log(L_P) = A_2+B_2N_P \,. \tag{35}$$

Cumulative oil production and accumulation of water production, accumulation of fluid production relations found to have low permeability reservoirs, water flooding rule curves $A$, $B$, $C$, $D$ can be represented.

## CONCLUSION

This paper presents and deduced considering the pressure gradient, the cumulative oil production and cumulative water production, the relationship between cumulative oil production and accumulation of fluid production. From low permeability reservoirs water flooding, four common regular pattern curves can be represented.

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