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# Demonstration Zone of "Water Control and Efficiency Improvement" in Area 1 of Laxi Block Study on fine liquid splitting method

Jiying Zhang

Geological Research Institute of No.6 Oil Production Plant of Daqing Oilfield Co., Ltd.) Daqing 163000, Heilongjiang

**Abstract.** Lamadian Oilfield has entered the late stage of ultra-high water cut development, and the producing conditions of each sublayer are different. In order to know the producing conditions of each sublayer more clearly, it is necessary to count the reserves and output conditions of each sublayer. Therefore, it is necessary to finely divide the liquid and oil production of each sublayer of the production well. The former liquid splitting method only considered the formation influencing factors, that is, the splitting method of formation coefficient, which could not meet the differences of different water cut in each sublayer at present. Through the research of fine liquid splitting method, we can clearly understand the production of each oil well layer in the block, the production status and adjustment potential of each sub-layer, thus guiding the adjustment and tapping potential of block layering measures. It provides a theoretical basis for the later development of ultra-high water cut block.

**Keywords:** Water control and efficiency improvement, Liquid volume splitting, Zone 1 of Labei West Block.

## 1. Introduction

Lamadian Oilfield has entered the late stage of ultra-high water cut development, and there are differences in the production status of each small layer. In order to better understand the production status of each small layer, it is necessary to make statistics on the reserves and production status of each small layer. Therefore, it is necessary to carry out fine splitting for the liquid and oil production of each small layer of the production well. The previous liquid volume splitting method only considers the formation influencing factors, that is, the formation coefficient splitting method, which can not meet the differences of different water content in each small layer. Considering the advantages of formation coefficient method in dynamic data splitting, on this basis, according to the development law of oil reservoir, considering that the difference of water saturation of small layer will lead to different seepage resistance of small layer, and the characteristics of oil-water phase permeability changing with the development of oil field, the oil-water phase permeability is considered as a function of water content by using the phase permeability curve of each oil layer, Through theoretical derivation, a new method for slicing production of oil wells is obtained. Reasonable splitting method comprehensively considers the influence of small layer permeability, effective thickness, small layer water saturation and measure data, and combined with profile test data, the splitting result is more accurate.

## 2. Ask questions

In order to know the production status of each sublayer more clearly, it is necessary to make statistics on the reserves and production status of each sublayer. Therefore, the liquid and oil production of each sublayer of the production well should be finely divided.

At present, the calculation of splitting coefficient at home and abroad mainly includes the following:

(1) Liquid production profile coefficient method;

(2) Effective thickness (H) method;

(3)Static split formation coefficient (KH) or flow coefficient method;

### 2.1 Profile test data method

Under a certain production pressure, the layered liquid production capacity of each small layer of the whole well can be reflected by the liquid production profile logging data. The logging data of liquid production profile can provide a reasonable basis for the dynamic analysis and allocation of production and water injection of oil and water wells in the oilfield.

Splitting process of cumulative oil production of sub layer:

(1) Make statistics on the logging data of previous liquid production profiles in the split time period;

(2) Comprehensive analysis of production history and process;

(3) Fine interpretation of logging data of previous liquid production profiles;
(4) Count the cumulative liquid production and oil production in the measure section of each well;
(5) Calculate the liquid production of each sublayer in each measure section or measurement section according to the relative liquid production carefully explained by the liquid production profile;
(6) Finally, the total liquid production and oil production of each small layer of a single well are calculated.

### 2.2 Effective thickness (H) method

This method was put forward at the early stage of splitting production, and its principle is to calculate the flow splitting coefficient of each pay zone by weighting the effective thickness h of pay zone. The effective thickness method was put forward in 1970s, which is used for qualitative analysis of ideal reservoir or production allocation estimation at the initial stage of oil and gas reservoir production, without considering various factors of porous media seepage characteristics, so this method is no longer used in dynamic analysis at present.
1.3 Static split formation coefficient (KH) or flow coefficient $\left(\frac{KH}{\mu}\right)$ method

This method is a further development based on the effective thickness method. Its principle is to use the formation coefficient KH to weight and calculate the oil production and liquid production splitting coefficient of each small layer of oil production well:

$$Y_i = \frac{K_i H_i}{\sum_{i=1}^{n} K_i H_i}$$

Where, Ki - effective permeability of the ith layer of the production well;
Hi - effective thickness of the ith sublayer of the production well;
Yi -- Static splitting coefficient.
From the above splitting equation, it can be seen that the parameters used in the traditional oil and water well production splitting scheme are relatively single, and the connectivity, differential pressure, material balance and energy balance of the reservoir are not fully considered. It is emphasized that the splitting results are effective for all reservoirs. However, some detection data such as liquid production and water injection profile effectively show that due to the influence of various factors of oil and water itself and the interaction between reservoirs in Multi-layer Reservoir, there will always be some reservoirs in multi-layer reservoir that can not be exploited for oil and gas. Obviously, this traditional production splitting scheme of oil and water wells is only applicable to those sandstone multi-layer reservoirs with relatively uniform reservoirs, short production well sections and few perforation layers, but not to those multi-layer reservoirs with uneven reservoirs, long production well sections and many perforation layers.

## 3. Determine the reasonable splitting method

Considering the advantages of formation coefficient method in dynamic data splitting, on this basis, according to the development law of oil reservoirs, considering that the difference of water saturation in small layers will lead to different seepage resistances in small layers, and the oil-water phase permeability is a characteristic that changes constantly with the development of oil fields, a new method of oil well production splitting by layers is obtained by theoretical deduction by applying the relative permeability curves of oil layers and considering the oil-water phase permeability as a function of water content.
Reasonable splitting method comprehensively considers the influence of permeability, effective thickness, water saturation and measure data of sublayer. Combined with profile test data, splitting results are more accurate.

### 3.1 Oil well production splitting

#### *3.1.1 Data processing*

(1) Treatment method of oil well liquid production profile
Compare the top and bottom depth of the sub layer boundary Library of the standard layer number with the top and bottom depth of the well section in the oil well profile library. If the well section top depth DA1 and well section bottom depth DA2 of horizon a in the oil well profile test library are within the range of top depth db1 and bottom depth DB2 of sublayer B in the sublayer boundary Library of the standard layer number, the horizon in the oil well profile test library is represented by the standard sublayer number B, and the corresponding top and bottom depths of this sublayer are DA1 and DA2. The corresponding well number, test date, thickness, daily liquid production and water content are the data corresponding to horizon a.
If the well section top depth DA1 and well section bottom depth DA2 of horizon a in the profile library are within the top and bottom depths of n small layers B, C and D ··· m in the small layer boundary Library of the standard layer number, and the top and bottom depths of small layers B, C and D ·· m are db1, DB2, DC1, DC2, dd1, DD2, DM1 and DM2 respectively, then small layer a in the profile library is changed into n small layers B, C and D ·· M, The corresponding top and bottom depths of these n sub layers are DA1, DB2, DC1, DC2, ···· DM1 and DA2 respectively. The corresponding well number, test date and water content are the data corresponding to layer a. the thickness and daily liquid production are calculated by the following formula:

$$h_B = d_{B2} - D_{A1} \quad (1)$$

$$h_C = d_{C2} - d_{C1} \quad (2)$$

$$h_M = D_{A2} - d_{M1} \quad (3)$$

$$Q_{lB} = \frac{1}{2} \times \frac{1}{n-1} \times Q_{lA} \quad (4)$$

$$Q_{lC}=\frac{1}{n-1}\times Q_{lA} \quad (5)$$

$$Q_{lM}=\frac{1}{2}\times\frac{1}{n-1}\times Q_{lA} \quad (6)$$

Type: $d_{C2}$—— the bottom depth of the well section of Layer C in the boundary library of small layers;

$h_M$ —— thickness of m layer in profile library;

$d_{M1}$ —— The top depth of the interval of layer M in the boundary library of small layers;

$n$ —— Number of layers in the boundary library of small layers;

$Q_{lM}$ —— Liquid production of M layer in profile library.

After processing the oil well profile test library according to the top depth and bottom depth of each sub-layer of each well in the sub-layer boundary library of standard layer number, the layers in the oil well profile library are all standard sub-layer numbers. If there are N sublayers A and B·M with the same well number and the same test time, the N sublayers will be merged, and the top and bottom depths of the corresponding well sections are DA1 and DM2. The corresponding well number and test date are the data corresponding to Layer A, and the thickness, daily liquid production and water cut are calculated by the following formula:

$$h_A=h_A+h_B+\cdots+h_M \quad (7)$$

$$Q_{lA}=Q_{lA}+Q_{lB}+\cdots+Q_{lM} \quad (8)$$

$$f_{wA}=\left(f_{wA}+f_{wB}+\cdots f_{wM}\right)/n \quad (9)$$

Where: $f_{wB}$ ——water content of layer A in oil well profile test library;

$f_{wB}$ —— Water content of layer B in oil well profile test library;

$f_{wM}$ —— Water content of M layer in oil well profile test library.

(2) Treatment method of oil well measure library

Extract well number, start date, completion date, measure name, measure mode, measure interval, top depth of construction interval and bottom depth of construction interval from oil well measure library. According to the top depth and bottom depth of each sub-layer of each well in the sub-layer boundary library of standard layer number, the oil well measure library is treated, and the measure intervals in the oil well measure library are represented by standard sub-layer number.

Firstly, the top and bottom depths of the sub-layer boundary library with standard layer number are compared with the top and bottom depths of the construction section in the oil well measure library.

If the top depth DA1 and bottom depth DA2 of the construction section of the measure section A in the measure library are within the range of top depth dB1 and bottom depth dB2 of the sub-layer B in the sub-layer boundary library of the standard layer number, the measure section in the measure library is represented by the standard sub-layer number B, and the top depth and bottom depth of the construction section corresponding to this sub-layer are DA1 and DA2 respectively. The corresponding well number, start date, completion date, measure name and measure mode are all data corresponding to interval A.

If the top depth DA1 and bottom depth DA2 of the construction well section of the measure layer A in the measure library are within the range of top and bottom depths of N sublayers in the sublayers boundary library B, C, D.M of standard layer number, the top and bottom depths of sublayers B, C, D.M are dB1, dB2, dC1, dC2, dD1, dD2, dM1 and dM2 respectively. The corresponding well number, start date, completion date, measure name and measure mode are all data corresponding to Layer A (same as produced fluid profile processing).

After the measure library is processed according to the top depth and bottom depth of each sub-layer of each well in the sub-layer boundary library of standard layer number, the layers in the oil well measure library are all standard sub-layer numbers. If there are N sub-layers A and B···M with the same well number and the same commencement date, the N sub-layers will be merged, and the top and bottom depths of the corresponding construction intervals are DA1 and DM2. The corresponding well number, start date, completion date, measure name and measure mode are all data corresponding to Layer A (same as produced fluid profile processing).

(3) Treatment method of oil well shooting hole library

The well number, serial number, date, reservoir group name, sublayer number, shooting thickness, effective thickness, permeability, formation coefficient, well section top depth and well section bottom depth are extracted from the shooting hole library. According to the sub layer boundary of the standard layer number and the top depth and bottom depth of each sub layer of each well in the library, the oil well shooting hole library is treated, and the oil reservoir group and sub layer number in the oil well shooting hole library are combined and expressed by the standard sub layer number.

First of all, shoot through the sub-layer with the effective thickness of 0 and the thickness of non-0. It is considered that only sandstone is developed instead of developing effectively. According to the literature research, the effective thickness is assigned according to the following formula:

$$h_{A\text{valid}}=1/2\times h_A \quad (10)$$

Where: $h_A$**valid** -effective thickness of layer A in oil well perforation library

The small layer with permeability of 0 in oil well perforation library is considered as the surface layer and the outer layer. According to the literature research, the value is assigned according to the following formula:

$$K_A=0.01 \quad (11)$$

Where: $K_A$ -Permeability of Layer A in perforation library

Compare the top and bottom depth of the sub-layer boundary library of standard layer number with the top and bottom depth of the well section in the oil well perforation library. If the interval top depth DA1 and interval bottom depth DA2 of sublayer A in the perforation library are within the range of interval top depth dB1 and interval bottom depth dB2 of sublayer B in the boundary library of standard layer number, the sublayer number in the perforation library is indicated by standard sublayer number B, and the interval top depth and interval bottom depth corresponding to this sublayer are DA1 and DA2 respectively. The corresponding well number, perforation date, perforation thickness, effective thickness, permeability and formation coefficient are all data corresponding to Layer A.

If the well section top depth DA1 and well section bottom depth DA2 of small layer a in the oil well shooting hole library are within the top and bottom depth of n small layers B, C and D ··· m in the small layer boundary Library of the standard layer number, and the top and bottom depths of small layers B, C and D ·· m are db1, DB2, DC1, DC2, dd1, DD2, DM1 and DM2 respectively, then small layer a in the oil well shooting hole library is changed into n small layers B, C and D ·· M, The corresponding top and bottom depths of these n sub layers are DA1, DB2, DC1, DC2, ···· DM1 and DA2 respectively. The corresponding well number, perforation date and permeability are the data corresponding to layer a. the perforation thickness, effective thickness, permeability and formation coefficient are calculated by the following formula:

$$h_B=\frac{1}{2}\times\frac{1}{n-1}\times h_A \quad (12)$$

$$h_C=\frac{1}{n-1}\times h_A \quad (13)$$

$$h_M=\frac{1}{2}\times\frac{1}{n-1}\times h_A \quad (14)$$

$$h_{B\text{valid}}=\frac{1}{2}\times\frac{1}{n-1}\times h_{A\text{valid}} \quad (15)$$

$$h_{C\text{valid}}=\frac{1}{n-1}\times h_{A\text{valid}} \quad (16)$$

$$h_{M\text{valid}}=\frac{1}{2}\times\frac{1}{n-1}\times h_{A\text{valid}} \quad (17)$$

$$K_B h_B=K_A\times h_{B\text{valid}} \quad (18)$$

$$K_C h_C=K_A\times h_{C\text{valid}} \quad (19)$$

$$K_M h_M=K_A\times h_{M\text{valid}} \quad (20)$$

Where: $h_M$ —— shooting thickness of layer m in the shooting hole library;

$h_{M\text{valid}}$ ——The effective thickness of layer m in the perforation library;

According to the sub layer boundary of the standard layer number, the horizon in the oil well shooting hole library is the standard sub layer number after the treatment of the shooting hole library according to the top depth and bottom depth of each sub layer of each well in the library. If there are n small layers A and B m with the same layer number and the same perforation time in the same well number, these n small layers shall be combined, and the top and bottom depths of the corresponding well section are DA1 and DM2. The corresponding well number and perforation date are the data corresponding to layer a. the perforation thickness, effective thickness, permeability and formation coefficient are calculated by the following formula:

$$h_A=h_A+h_B+\cdots+h_M \quad (21)$$

$$h_A=h_A+h_B+\cdots+h_M \quad (22)$$

$$h_{A\text{valid}}=h_{A\text{valid}}+h_{B\text{valid}}+\cdots+h_{M\text{valid}} \quad (23)$$

$$K_A=\frac{\sum_{i=1}^{n}\left(K_i h_{i\text{valid}}\right)}{\sum_{i=1}^{n} h_{i\text{valid}}} \quad (24)$$

$$Kh=K_A\times h_{A\text{valid}} \quad (25)$$

(4) Data processing method of relative permeability curve According to the relative permeability data of 7 groups of Sa II oil layer group, Sa III oil layer group, Pu I1 and Pu I2 oil layers, Pu I4-7 and Pu II oil layers, Gao I and Sa I oil layers, Gao II oil layer group and Gao III oil layer group provided by coring wells, 7 curves of the relationship between water cut and relative permeability of oil-water phase are made according to the diversion equation, as shown in the figure below.

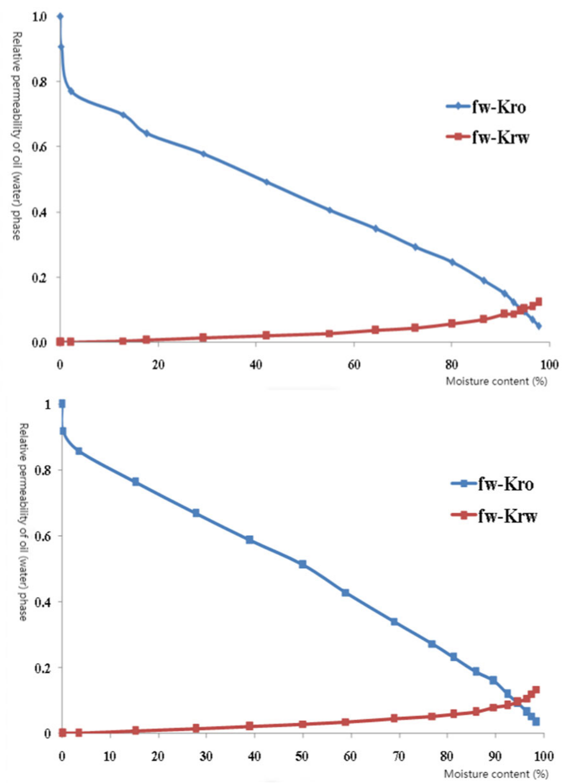


**Fig. 1** Relationship curve between water cut and relative permeability of oil-water phase in SAII and III oil-bearing formation

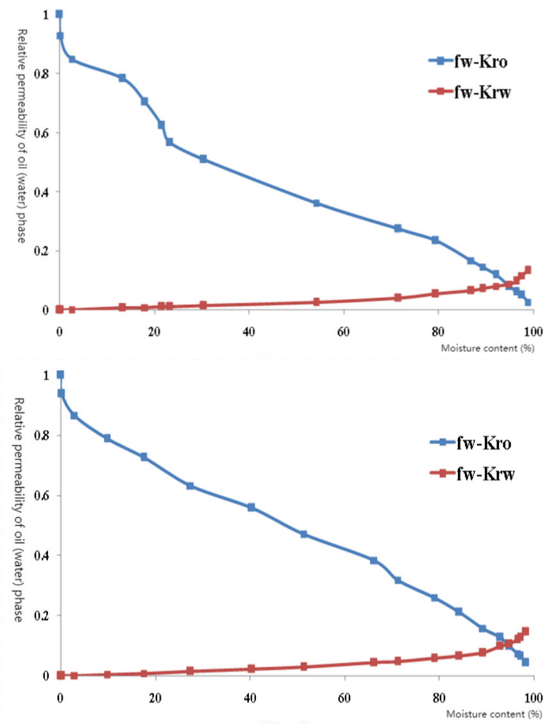


**Fig. 2** Relationship curve between water cut and oil-water phase relative permeability of oil layers of Portugal I1, Portugal I2, Portugal i4-7 and Portugal II

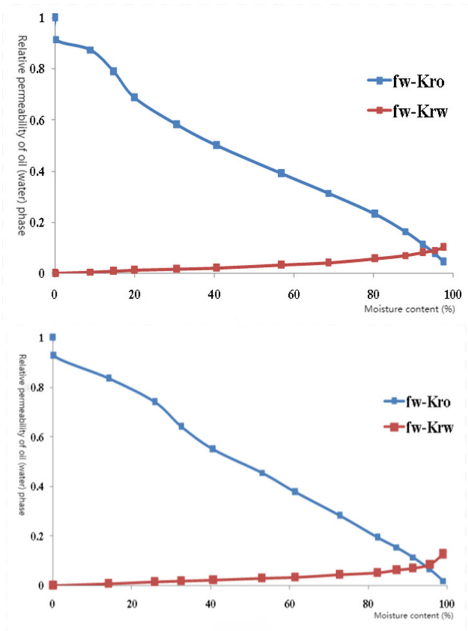


**Fig. 3** Relationship curve between water cut and relative permeability of oil-water phase in gaoi, SAII and gaoii reservoir groups

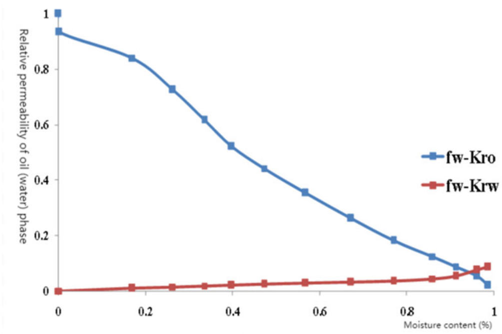


**Fig. 4** Relationship curve between water cut and relative permeability of oil-water phase in gaoiii oil reservoir group

### *3.1.2 Establish dynamic data splitting model*

The production period is divided into water cut period and water cut period according to the water cut of the oil well. Therefore, the production period is divided into two reasonable production periods according to the water cut of the oil well.

(1) Anhydrous production period ( $f_w = 0$ )

From the initial stage of production (or full water injection) to the obvious water breakthrough, that is, the anhydrous oil production period, the oil phase permeability remains unchanged, and the reasonable splitting method is the same as the KH value method. The principle is to calculate the oil production splitting coefficient of each small layer of oil production well by weighting the formation coefficient Kh.

The splitting formula is as follows:

$$q_{oi} = \frac{R_i k_i h_i}{\sum_{i=1}^{n} R_i k_i h_i} Q_o \tag{26}$$

Where: $k_i$ —permeability of the first sublayer of the oil well, $\mu m^2$ ;

$h_i$ —— Effective thickness of the first sublayer of the oil well, $m$ ;

$q_{oi}$ —— Oil production of the first sublayer, 104t; ;

$Q_o$ —Total oil output of oil well, 104t,

$R_i$ —— Measures to increase production coefficient of sublayer I.

When the production of the sub-layer with measure data is split, the effective period of stimulation is one year, and the coefficient of measure stimulation is determined according to the actual effect of stimulation measures taken by oil producing wells. Referring to the stimulation coefficient of Daqing Oilfield, it is determined that the stimulation coefficient is 1.05 after fracturing measures, 1.02 after acidizing measures, 0 after water plugging measures and 1 after plugging measures.

When the oil wells with the output profile test data at time T in the waterless oil production period are split, the split results of sub-layers are obtained according to the reasonable split method, and then the split results are verified by the output profile test data.

First, calculate the oil production and the sum of water production of sub-layers and the ratio of test output of each sub-layer to the sum of test data according to the test data of output profile, and then use the obtained sub-layer splitting results and test data ratio to correct the splitting results of these sub-layers, as shown in the following formula:

$$q_{coi} = \frac{q_{ico} \times t_i}{\sum_{i=1}^{n} \left(q_{ico} \times t_i\right)} \sum_{i=1}^{n} q_{oi} \tag{27}$$

Where: $q_{coi}$ ——corrected oil production of layer I;

$q_{ico}$ ——Test oil production of layer I in the production profile database;

$t_i$ ——Production days corresponding to time t in well history database;

$q_{oi}$ ——Oil production of layer I;

$n$ ——The number of small layers with production profile test data.

(2) Water breakthrough production period( $0 < f_w < 1$ )

After water breakthrough, the oil-water phase permeability changes with the continuous change of water content. The functional relationship between water content and oil phase relative permeability can be obtained through the relative permeability curves of various oil layers. The oil phase relative permeability corresponding to the water content of different small layers can be calculated by interpolation method, and then the oil well production can be divided. The splitting formula is as follows:

$$q_{oi} = \frac{R_i k_i \varphi_{io}(f_{wi}) h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{io}(f_{wi}) h_i} Q_o \tag{28}$$

$$q_{wi} = \frac{R_i k_i \varphi_{iw}(f_{wi}) h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{iw}(f_{wi}) h_i} Q_w \tag{29}$$

Where: $q_{wi}$ ——the water yield of sublayer I;

$\varphi_{io}(f_{wi})$ —— Relative permeability of oil phase in the first sublayer;

$\varphi_{iw}(f_{wi})$ —— Relative permeability of water phase in sublayer I;

$f_{wi}$ —— layered water content of the I-th sublayer;

$R_i$ —— Measures to increase production coefficient of sublayer I.

When splitting the production of small layers with measure data, the effective period of stimulation is one year, and the measure stimulation coefficient is determined according to the actual effect of stimulation measures taken by production wells. Referring to the stimulation coefficient of Daqing Oilfield, after the implementation of fracturing measures, the stimulation coefficient of measures is 1.05; After the implementation of acidizing measures, the stimulation coefficient is 1.02; After the implementation of water shutoff measures, the stimulation coefficient is 0; After the plug pulling measures are implemented, the stimulation coefficient is 1.

For the production splitting of oil wells with production profile test data at time t in water breakthrough production period, after the small layer splitting results are obtained according to the reasonable splitting method, the production profile test data is used to verify the splitting results.

Firstly, according to the test data of production profile, calculate the total oil and water production of small layers and the proportion of test production of each small layer to the total test data, and correct the splitting results of these small layers by using the obtained splitting results of small layers and the proportion of test data, as shown in the following formula:

$$q_{coi} = \frac{q_{ico} \times t_i}{\sum_{i=1}^{n} \left(q_{ico} \times t_i\right)} \sum_{i=1}^{n} q_{oi} \tag{30}$$

$$q_{cwi} = \frac{q_{icw} \times t_i}{\sum_{i=1}^{n} \left(q_{icw} \times t_i\right)} \sum_{i=1}^{n} q_{wi} \tag{31}$$

Where: $q_{cwi}$ ——corrected water yield of the i-th layer;

$q_{icw}$ ——The test water yield of the i-th layer in the production profile database.

#### *3.1.3 Solution of model*

(1) The first moment of water breakthrough in oil well t = 1

For specific oil wells, the first water breakthrough time is time t, and the water cut of the whole well is

$$f_w^{(1)} = \frac{Q_w^{(1)}}{Q_o^{(1)} + Q_w^{(1)}} \tag{32}$$

At the first moment of water breakthrough, the permeability of each small layer is different, resulting in different water content of each small layer. In order to obtain the layered water cut of each small layer at the first time of water breakthrough, the average permeability of the oil well must be determined by the method of thickness weighted average. The specific formula is as follows:

$$\bar{k} = \frac{\sum_{i=1}^{n} \left(k_i h_i\right)}{\sum_{i=1}^{n} h_i} \tag{33}$$

Through the relationship between the permeability of each small layer opened by the oil well and the average permeability of the oil well, combined with the water cut of the whole well, determine the water cut $f_{wi}^{(0)}$ of the small layer at the first time of water breakthrough.

$$f_{wi}^{(0)}=\frac{k_i}{\bar{k}}\times f_w^{(0)} \quad (34)$$

Without considering the influence of capillary force and gravity, the oil-water two-phase diversion equation mainly depends on the ratio of oil-water viscosity and relative permeability. For a specific reservoir, $\mu_o$ and $\mu_w$ values are basically unchanged in the development process. Therefore, the change of $f_{wi}$ is mainly affected by $K_{ro}$ / $K_{rw}$.

$$f_{wi}^{t(1)}=\frac{Q_w^{t(1)}}{Q_w^{t(1)}+Q_o^{t(1)}}=\frac{-\frac{k_{wi}}{\mu_{wi}}A\frac{dp}{dx}}{-\left(\frac{k_{wi}}{\mu_w}+\frac{k_{oi}}{\mu_o}\right)A\frac{dp}{dx}}=\frac{1}{1+\frac{\mu_w}{\mu_o}\frac{K_{roi}}{K_{rwi}}} \quad (35)$$

Where: $f_{wi}^{t(1)}$ ——moisture content at time t (1) of the small layer,%;

$\frac{\mu_w}{\mu_o}$ ——Water oil viscosity ratio under formation conditions;

$\frac{K_{roi}}{K_{rwi}}$ ——The oil-water relative permeability ratio of the small layer under formation conditions.

According to the data provided by the laboratory, the water phase viscosity is $\mu_w$=**0.6** and the oil phase viscosity is $\mu_o$=**10.3**.

Different relative permeability curves are selected according to the different reservoir groups to which the small layer belongs. Using the relevant data in the relationship curve between water cut and oil-water relative permeability, the layered water phase relative permeability $K_{rwi}$, i.e. $\varphi_{iw}(f_w^{t(0)})$ and oil phase relative permeability $K_{roi}$, i.e. $\varphi_{io}(f_w^{t(0)})$ corresponding to water cut of different small layers are obtained by linear interpolation method.

The oil production of small layer is obtained by the following splitting formula:

$$q_{oi}^{t(1)}=\frac{R_i k_i \varphi_{io}(f_{wi}^{t(0)})h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{io}(f_{wi}^{t(0)})h_i}Q_o^{t(1)} \quad (36)$$

The water production of small layer of oil well is obtained by the following splitting formula:

$$q_{wi}^{t(1)}=\frac{R_i k_i \varphi_{iw}(f_{wi}^{t(0)})h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{iw}(f_{wi}^{t(0)})h_i}Q_w^{t(1)} \quad (37)$$

Where: $q_{wi}$ ——water production of the small layer, 104t;

$Q_w$ ——Total water production of oil well, 104t.

(2) Any time after water breakthrough of oil well (T > t)

At any time t after water breakthrough, for the small layer with production splitting at the previous time, the layered water content is determined by the layered water content at the previous time.

$$f_{wi}^{T-1}=\frac{q_{wi}^{T-1}}{q_{wi}^{T-1}+q_{oi}^{T-1}} \quad (38)$$

After the layered water cut is determined, different relative permeability curves are selected according to the different reservoir groups to which the small layer belongs. Using the relevant data in the relationship curve between water cut and oil-water relative permeability, the layered water phase relative permeability $K_{rwi}$, i.e. $\varphi_{iw}(f_{wi}^{T-1})$ and oil phase relative permeability $K_{roi}$, i.e. $\varphi_{io}(f_{wi}^{T-1})$ corresponding to the water cut of different small layers are obtained by linear interpolation method.

The specific formula of oil production and water production splitting is as follows:

$$q_{oi}^{(T)}=\frac{R_i k_i \varphi_{io}(f_{wi}^{(T-1)})h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{io}(f_{wi}^{(T-1)})h_i}Q_o^{(T)} \quad (39)$$

$$q_{wi}^{(T)}=\frac{R_i k_i \varphi_{iw}(f_{wi}^{(T-1)})h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{iw}(f_{wi}^{(T-1)})h_i}Q_w^{(T)} \quad (40)$$

For the small layer of newly patched holes, it shall be split according to the time of first water contact. The layered water cut is determined according to the relationship between the permeability of the small layer and the average permeability of the oil well. The specific formula is as follows:

$$f_{wi}^{(T)}=\frac{k_i}{\bar{k}}\times f_w^{(T)} \quad (41)$$

After the layered water cut is determined, different relative permeability curves are selected according to the different reservoir groups to which the small layer belongs. Using the relevant data in the relationship curve between water cut and oil-water relative permeability, the layered water phase relative permeability $K_{rwi}$, i.e. $\varphi_{iw}(f_{wi}^{T})$ and oil phase relative permeability $K_{roi}$, i.e. $\varphi_{io}(f_{wi}^{T})$ corresponding to the water cut of different small layers are obtained by linear interpolation method.

The specific formula of oil production and water production splitting is as follows:

$$q_{oi}^{(T)}=\frac{R_i k_i \varphi_{io}(f_{wi}^{(T)})h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{io}(f_{wi}^{(T)})h_i}Q_o^{(T)} \quad (42)$$

$$q_{wi}^{(T)}=\frac{R_i k_i \varphi_{iw}(f_{wi}^{(T)})h_i}{\sum_{i=1}^{n} R_i k_i \varphi_{iw}(f_{wi}^{(T)})h_i}Q_w^{(T)} \quad (43)$$

## 4. What do you know

3.1Through the investigation of literature, the conventional splitting methods are summarized and analyzed. Considering that the difference of water saturation of small layers will lead to different seepage resistance of small layers, the water saturation of small layers is taken as an important factor in the reasonable splitting method determined in this paper. Reasonable splitting method comprehensively considers the influence of small layer permeability, effective thickness, small layer water saturation and measure data, and combined with profile test data, the splitting result is more accurate.
3.2According to the reasonable splitting method, the relevant calculation auxiliary program is compiled to split the production of 269 oil wells in the research block, which reduces the complexity of manual operation and greatly improves the calculation speed and accuracy.

## References

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