

# **The Algorithm Study on Calculating Formation Parameters under the Log-Log Coordinate System in the Well-Testing Interpretation Model of Commingling Production Multi-Stage Fractured Vertical Well**

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## **Abstract**

For a reservoir characteristic of a multilayer, commingling production is an effective way of exploitation. Especially for the well characteristic of multi-layered in tight reservoirs of Lucaogou Formation in Xinjiang Oilfield, it must adopt the approach of commingling production with staged-fractured to mine.

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And so, in the well-testing interpretation software (referred WTIS), integrating the well-testing interpretation model (referred WTIM) of commingling production multi-stage fractured vertical well (referred CPMSFVW) has important practical economic and social value; therefore, it is particularly necessary to study the algorithm of calculating formation parameters under the log-log coordinate system (referred CFPLLCS) of this model. This paper firstly discussed the realization process of CFPLLCS in the WTIS, and then from the WTIM of the CPMSFVW, gave its dimensionless parameters definition, finally on the basis of the above, gave the step and algorithm of CFPLLCS of the WTIM of the CPMSFVW. The realization of the algorithm laid a necessary foundation for finally integrating the WTIM of the CPMSFVW in the WTIS.

**Mathematics Subject Classification:** 68W99; 68U99; 76-04

**Keywords:** Commingling Production Multi-Stage Fractured; Calculating Formation Parameters under Log-log Coordinate System; Well-Testing Interpretation Software; Algorithm Research

## 1 Introduction

Due to the influence of the deposition process, there is strong vertical direction heterogeneity in many reservoirs, which exhibits the characteristics of a multilayer [1]. The development of such oil and gas wells usually adopts the way of commingling production or layered mining to produce [2]. In order to improve the productivity of single well, many production wells in mines are using the way of commingling production [1]. Especially for multilayer reservoir with poor physical property and smaller thickness, commingling production has become effective means of its efficient development [3]. As for part wells with multilayer characteristics in Xinjiang oilfield of Lucaogou Formation reservoir, because they are tight reservoir, the monolayer productivity is very low, so mostly adopt the

approach of commingling production with multi-stage fractured to mine. Therefore, in the well-testing interpretation software (referred WTIS), integrating the well-testing interpretation model (referred WTIM) of commingling production with multi-stage fractured vertical well (referred CPMSFVW) has important practical economic and social value.

The essence of the WTIS is still a simulation of artificial fitting process [4], therefore in the development process of WTIS, need fitting the measured pressure difference curve and theoretical charts under the log-log coordinate, and then calculate formation parameters by the fitting results [4-6]. Literature survey shows that there are more literatures, which discuss and analysis the WTIM of the commingling production vertical [1-3, 7-27], and relatively small literatures, which discuss and analysis the WTIM of the CPMSFVW [28-31], but there are a few research reports about calculating formation parameters under the log-log coordinate system (referred CFPLLCS) of the WTIM of the CPMSFVW.

Based on the realization process of developing WTIS, combined with the characteristic of the WTIM of the CPMSFVW, this paper gave the algorithm of CFPLLCS of this model.

## 2 Study on the process of CFPLLCS in WTIS

At an early stage, due to the lack of WTIS, people adopted manually fitting charts to calculating formation parameters during the time of well test interpretation. The procedure is as follows: The first step drew respectively the charts and the curve, which is the relation between the measured pressure difference ( $\Delta p = P_i - p_{wf}(t)$ ) and the time difference ( $\Delta t = t_i - t_0$ ), in the two sheet of transparent paper with exactly the same size and log-log coordinate system. The second step moved parallel the measured pressure difference in the vertical and horizontal direction, while parallel moving should always keep the two log

coordinate axes parallel to each other, and then found one curve of the best fitting with the measured curve in charts. Finally, selected the appropriate fitting points, and calculated formation parameters according to the pressure fitting values and time fitting values [4]. Seen from the above operation process, while CFPLLCS, the solving parameters process in the WTIS is essentially still a simulation of the solving parameters process in artificial fitting, this process can be illustrated in Figure 1.

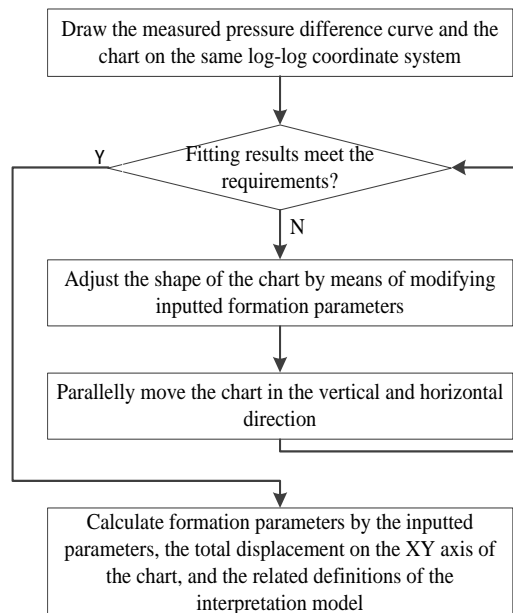


Figure 1: The Flow chart of CFPLLCS in the WTIS

From Figure 1, in the WTIS, firstly drew the measured pressure difference curve and the chart under the same log-log coordinate system, and then adjusted the shape of the chart by the inputted parameters to make the chart as far as possible similar to the measured pressure difference curve, then parallely moved the chart in the vertical and horizontal direction to make the chart as much as possible coincide with the measured pressure difference curve. In the above process, the

adjustment parameters and parallel movement generally needed adjust repeatedly to achieve the best fitting effect. Finally, calculated formation parameters by these known quantity: the inputted parameters, the total displacement on the XY axis of the chart and the related definitions of the interpretation model.

In the above-described process, the role of the total displacement on the XY axis of the chart is discussed as follows. The process of parallelly movement can be illustrated in Figure 2. The dotted line L in the figure is the measured pressure difference log-log curve, and the solid line L' is theoretical log-log chart, which is most similar to the measured pressure difference log-log curve in many theoretical log-log charts (that is to say, its fitting results is the best). Assuming that L' achieves the best fitting effect after respectively moving  $\Delta X$  units in X-axis and  $\Delta Y$  units in Y-axis, that is to say, the coincidence effect of the two curves achieves the best results at this time.

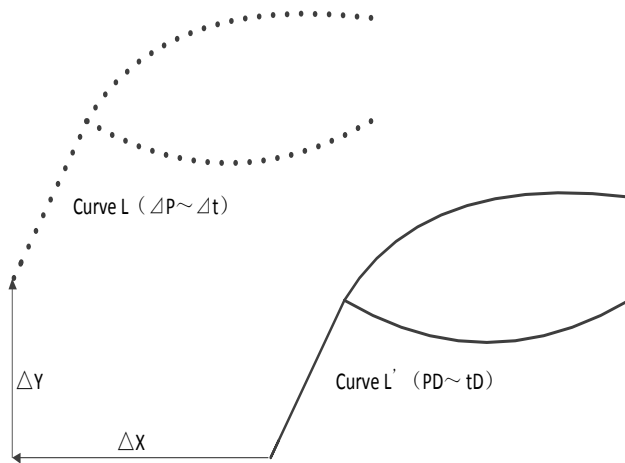


Figure 2: The diagram of parallelly moving the chart in WTIS

On the curve L and L', respectively takes the first point for the observation point, assume their coordinates are respectively  $(\Delta t_1, \Delta p_1)$  and  $(tD_1, pD_1)$ , and suppose that the coordinate of the first point on the moved curve L' is  $(tD'_1, pD'_1)$ .

According to the characteristics of log-log coordinates system [32], at this time, there are:

$$\Delta X = \lg(tD_1') - \lg(tD_1) \quad (1)$$

$$\Delta Y = \lg(pD_1') - \lg(pD_1) \quad (2)$$

When achieves the best fitting effect, namely thinks that the curve L and L' coincide on every point at this time, there are:

$$\Delta t_1 = tD_1' \quad (3)$$

$$\Delta p_1 = pD_1' \quad (4)$$

After putting the formula (3) into the formula (1) and inserting the formula (4) in the formula (2), the result can be obtained:

$$\frac{\Delta t_1}{tD_1} = 10^{\Delta X} \quad (5)$$

$$\frac{\Delta p_1}{pD_1} = 10^{\Delta Y} \quad (6)$$

Because the observation point is taken randomly, therefore, for every fitting points (two points can be coincided at the best fitting results) on the curve L and curve L', there should be:

$$\frac{\Delta t}{tD} = 10^{\Delta X} \quad (7)$$

$$\frac{\Delta p}{pD} = 10^{\Delta Y} \quad (8)$$

The tD and pD in the above formula is respectively the dimensionless time and dimensionless pressure of the WTIM, which are given by the specific WTIM. Therefore, in the WTIS, according to the WTIM selected by users, formation parameters can be calculated by the formula (7)-(8).

### 3 The research of CFLLCS of CPMSFVW

#### 3.1 Study on the WTIM of the CPMSFVW

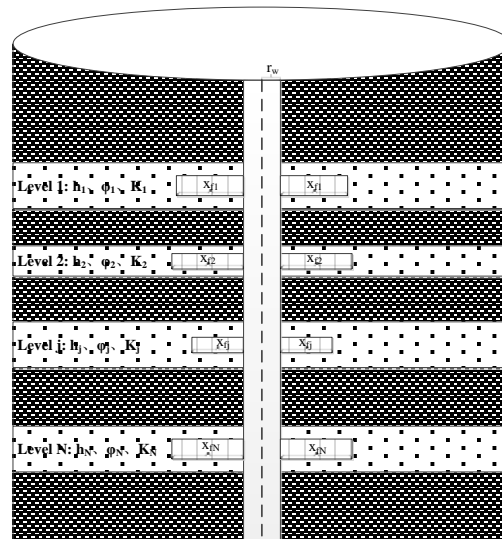


Figure 3: The WTIM of the CPMSFVW

The WTIM of the CPMSFVW is shown in figure 3. According to the model, make assumptions as following: 1) The reservoir is homogeneous, uniform thickness and isotropic; 2) The fluid is single-phase and slightly compressible, the  $C_t$  of comprehensive compression coefficient, the  $\mu$  of viscosity and the  $B$  of volume coefficient are constant. The Thickness, porosity and permeability in  $j$ -layer is respectively  $h_j$ ,  $\phi_j$  and  $K_j$ , and the value of them cannot change with time; 3) Before the oil well open and produce, in every small layer and between the layers, the original reservoir pressure equal everywhere, are all  $P_i$ ; 4) The radius of the well is  $r_w$  and the yield of the well is the given  $q$ . After the well open and produce, yield of each small layer can varie with time, but the  $q$  of all layer yield sum remains unchanged. There is an impermeable barrier between any two adjacent layers, so there is no cross-flowing between layers, and can only communicate with each other at the bottom of the well; 5) The process of flow and

testing are both the isothermal process; 6) Ignoring the influence of gravity and capillary force.

Suppose that N layers produce together, and define dimensionless quantities as follows:

The relationship between the dimensionless pressure  $pD_j$  and the measured pressure  $p_j$  in the j- layer is as follows:

$$pD_j = \frac{\sum_{i=1}^N K_i h_i}{1.842q\mu B} [P_i - p_j] \quad (9)$$

The relationship between the dimensionless pressure  $pD_w$  and the measured pressure  $p_w$  at the bottom hole is as follows:

$$pD_w = \frac{\sum_{i=1}^N K_i h_i}{1.842q\mu B} [P_i - p_w] = \frac{\sum_{i=1}^N K_i h_i}{1.842q\mu B} \Delta p_w \quad (10)$$

The relationship between the dimensionless time  $tD_j$  in the j-layer and the test time t is as follows:

$$tD_j = 3.6 \times 10^{-3} \sum_{j=1}^N \frac{K_j}{x_{ff}^2 \phi_j \mu C_t} t \quad (11)$$

The relationship between the dimensionless wellbore storage coefficient  $CD_j$  in the j-layer, the wellbore storage coefficient C and the fracture half-length  $x_{ff}$  in the j-layer is as follows:

$$CD_j = \frac{C}{2\pi \sum_{i=1}^N (\phi h)_i C_t} \frac{1}{x_{ff}^2} \quad (12)$$

The relationship between the dimensionless fracture conductivity  $KfwD_j$  and the fracture conductivity  $Kfw_j$  in the j-layer is as follows:

$$KfwD_j = \frac{Kfw_j}{x_{ff} K_j} \quad (13)$$



The flow coefficient ratio (Also called the yield contribution rate)  $\xi_j$  in the j-layer defines as follows:

$$\xi_j = \frac{\left(\frac{Kh}{\mu}\right)_j}{\sum_{i=1}^N \left(\frac{Kh}{\mu}\right)_i} = \frac{K_j h_j}{\sum_{i=1}^N K_i h_i} \quad (14)$$

The storage capacity ratio  $\omega_j$  in the j-layer defines as follows:

$$\omega_j = \frac{C_t(\phi h)_j}{\sum_{i=1}^N (\phi h)_i C_t} \quad (15)$$

### 3.2 Algorithm research of CFPLLCS of CPMSFVW

Known from the formula (10):  $\frac{pD_w}{\Delta p_w} = \frac{\sum_{i=1}^N K_i h_i}{1.842q\mu B}$ ,  $\frac{pD_w}{\Delta p_w} = \frac{\sum_{i=1}^N K_i h_i}{1.842q\mu B} \cdot \frac{pD_w}{\Delta p_w}$

is the ratio of measured dimensionless pressure  $pD_w$  and measured pressure  $\Delta p_w$  at bottom-hole, its physical meaning is consistent with  $\frac{pD}{\Delta p}$  in the formula (8). Therefore, the result can be obtained by using of combining the formula (8) and (10):

$$\sum_{i=1}^N K_i h_i = 1.842q\mu B \times 10^{-\Delta Y} \quad (16)$$

Because the flow coefficient ratio  $\xi_j$  is a parameter of calculation chart, in other words, its value can impact the chart shape and when the chart is being moved, its value will not change. Therefore the permeability  $K_j$  of each layer can be calculated by using of combining the formula (14) and (16):

$$K_j = \frac{\xi_j \cdot \sum_{i=1}^N (Kh)_i}{h_j} = \frac{1.842q\mu B \xi_j}{h_j 10^{\Delta Y}} \quad (17)$$

Similarly, the physical meaning of  $\frac{tD}{\Delta t}$  in the formula (7) is consistent with  $\frac{tD_j}{t}$  in the formula (11); therefore the result can be obtained by using of combining the formula (7) and (11):

$$10^{-\Delta X} = 3.6 \times 10^{-3} \sum_{j=1}^N \frac{K_j}{x_{fj}^2 \phi_j \mu C_t} \quad (18)$$

and by the formula (12) shows that:

$$x_{fj} = \sqrt{\frac{C}{CD_j C_t \cdot 2\pi \sum_{i=1}^N (\phi h)_i}} \quad (19)$$

After putting it into the formula (18) the result can be obtained:

$$C = 3.6 \times 10^{-3} \cdot 10^{\Delta X} \cdot 2\pi \sum_{i=1}^N (\phi h)_i \cdot \sum_{j=1}^N \left[ \frac{CD_j K_j}{\phi_j \mu} \right] \quad (20)$$

In the above formula,  $CD_j$  is a parameter of calculation chart, so the wellbore storage coefficient  $C$  can be calculated by the formula (20). After that, the fracture half-length  $x_{fj}$  can be computed by putting the calculated  $C$  into the formula (19).

By the formula (13) shows that:

$$Kfw_j = KfwD_j \cdot x_{fj} \cdot K_j \quad (21)$$

Because the dimensionless fracture conductivity  $KfwD_j$  in the  $j$ -layer is a parameter of calculation chart, so the fracture conductivity  $Kfw_j$  in the  $j$ -layer can be calculated by putting  $KfwD_j$  and  $x_{fj}$ ,  $K_j$  into the formula (21).

Algorithm research of CFPLLCS of the WTIM of the CPMSFVW in the WTIS is summarized as follows:

1) Obtain  $\Delta X$  and  $\Delta Y$  value of the accumulative total displacement of the chart by the software recording.

- 2) Calculate the permeability  $K_j$  in the j-layer using the parameter  $\xi_j$  of calculation chart and  $\Delta Y$  by the formula (17).
- 3) Calculate the wellbore storage coefficient C using the parameter  $CD_j$  of calculation chart and  $\Delta X$  by the formula (20).
- 4) Calculate the fracture half-length  $x_{ff}$  in the j-layer by putting the calculated C into the formula (19).
- 5) Calculate the fracture conductivity  $Kfw_j$  in the j-layer using the parameter  $KfwD_j$  of calculation chart and calculated  $K_j, x_{ff}$  by the formula (21).
- 6) Directly calculate the storage capacity ratio  $\omega_j$  in j-layer by the formula (15).
- 7) Display the calculated parameters to the interface in the WTIS.

## 4 Conclusions

- 1) The process of CFPLLCS in the WTIS has been discussed. In the above process, the role of total displacement  $\Delta X, \Delta Y$  of the chart on the XY axis and the dimensionless parameter definition of specific WTIM has been pointed out.
- 2) From the WTIM of CPMSFVW, the relevant dimensionless parameters definition has been given.
- 3) The steps and algorithm formula of CFPLLCS of the WTIM of the CPMSFVW in the WTIS have been given.

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