

## The research on well pattern adjustment strategy of PL oilfield

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**Abstract:** PL oilfield adopts commingled production with big intervals, which causes serious conflict among layers, so layer system and well pattern adjustment of later stage is required, at this time we will need to determine the scope of the reasonable well spacing. Three main pay formations of PL oilfield has a big difference in crude oil viscosity, which also have different reservoir property. On the basis of the analysis of actual production condition, numerical simulation model is set up separately for each reservoir. Results showed that the ultimate recovery degree under different well spacing were similar with the present condition of mining. But with the increase of well spacing, the increased amplitude of the recovery degree becomes smaller than before, the time to achieve the ultimate recovery increases. In order to further determine the scope of the rational well spacing, the concept of pseudo oil production rate is introduced. On the basis of the actual oil production rate, determine the scope of the reasonable well spacing of each reservoir on the condition that the pseudo oil production rate was 2%, and analyze its reasons. Considering the practical mining conditions and the drilling cost, the layer combination and well pattern of PL oilfield has been adjusted, its development effect and economic benefits are predicted through the numerical simulation model. The research for PL oilfield late development adjustment provides a certain theoretical basis, which also has guiding significance for other oilfields to improve development effect.

### Introduction

Determining reasonable injection-production well spacing is a very important factor to consider when well pattern adjustment at later stage of oilfield is needed and how to improve the oilfield development effect. If the injection-production well spacing is too small, more new well is needed, which causes big well spacing density and increases the economic costs. As the drilling cost and oil price fluctuate, it will increase the risk of oilfield development. If injection-production well spacing is too large, the pressure cost will increase between the injection well and the production well. The water driving sweep efficiency decreases so that water flooding effect is poor for strong heterogeneity reservoirs. Therefore we need to determine reasonable well spacing so that oilfield can obtain the best development effect and economic benefit [1,2,3,4,5]. At present, the reasonable injection-production well spacing mostly aims at low permeability reservoirs. Based on its main contradictions, mainly consider start-up pressure gradient, combine with the technical limit well spacing and the economic reasonable well spacing, and then determine the reasonable well spacing

[5-8]. But for high permeability conventional reservoir, the main research is about its oil production rate, water driving control degree, the ultimate recovery efficiency and so on. Due to the good displacement relationship between the injection well and the production well under different well spacing, the research about rational injection-production well spacing for high permeable reservoir is less. Well spacing do not have a significant influence on the ultimate recovery of high permeability reservoir. Therefore it is difficult to determine the scope of the reasonable well spacing through the ultimate recovery degree [6,7,8,9,10,11,12].

In order to determine the scope of reasonable well spacing like such reservoir, provide certain theoretical basis for this kind of reservoir development, this paper proposes a new method of research and application of numerical simulation model. By introducing the concept of pseudo oil production rate, determine reasonable well spacing under different pseudo oil production rate. On this basis of this, well pattern adjustment scheme of PL oilfield formation is set up, and numerical simulation predicting results show that good development effect can be obtained.

### **The brief introduction of oilfield**

**Geological characteristics.** PL oilfield is located in the central and southern area of BH sea, from top to bottom, it contains group P of neogene, group MHZ of neogene and group GT of neogene, group DY of paleogene, group SHJ of paleogene, group KD of paleogene and cretaceous strata. Group lower MHZ and group GT is the main pay production layer of the oilfield. Group lower MHZ is mainly mudstone at the top, with thin layer sandstone. At the medium and bottom part, it exists sand shale interbed. Group GT formation is mainly fine-grained sandstone, fine sandstone, with thin layers of mudstone. The main pay production layers is divided into 5 sections at the group lower MHZ, namely from oil section L00 to L40. Upper Group GT is divided into three sections, namely from oil group L50 to L70, group lower GT is divided into five sections, namely from oil group L80 to L120., The porosity of the group lower MHZ ranges from 23.5% to 34.7%, the average value is 28%; Permeability ranges mainly from 17mD to 2200mD, which is generally greater than 50mD, the average value is 1627md. Group MHZ has high permeability and high porosity. The porosity of the group upper GT ranges from 20.6% to 32.6%, the average value is 27%; Permeability ranges mainly from 15mD to 2330mD, which is generally greater than 50mD, the average value is 1555mD. Group GT has high permeability and high porosity. The porosity of the group lower GT ranges from 18.9% to 30.0%, the average value is 23.3%; Permeability ranges mainly from 18mD to 5900mD, it ranges mainly from 50mD to 1000mD, the average value is 936md. It has high permeability and medium-high porosity.

**The brief development situation.** PL oilfield adopts inverted nine spot flooding pattern to do the water driving development, it is mainly about commingled production with big intervals, layered water injection is a complementary way of water injection. Group MHZ has high crude oil viscosity, it is from 78.7 mPa s to 262.8 mPa s, which belongs to the category of heavy oil, The oil viscosity of group GT is less than 50mpa • s. Group GT belongs to the conventional crude oil, the difference of crude oil properties is obvious; Production dynamic data shows that group MHZ has a lower capacity, Interlayer interference is bigger when group MHZ is combined with group GT. The contribution of Group MHZ is small, so take a set of formation to do the development, the main production interval is group GT, some developing well use the bottom of group MHZ. Due to imperfect injection-production system, the formation is void and serious, it is essential to adjust well pattern.

### Reasonable injection-production well spacing

**Setting up the model.** Using numerical simulation software of Eclipse, set up the single numerical simulation model for the group lower MHZ, the group upper GT and the group lower GT respectively, the grid size of the model is 5 m x 5 m, the injection-production well spacing for design is 125m , 150m ,175m, 200m and 225m, 250m, 275m, 300m, 325m and 350m. A numerical simulation model is shown in Fig. 1. Well P1 is a production well, well I1 is a injection well, coordinates of oil and water wells under various well spacing grid number are shown in Table 1.

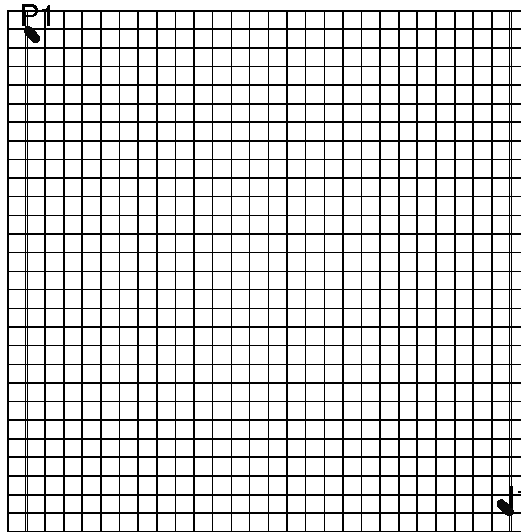


Fig. 1 a model for the numerical simulation

Table 1 designing table of numerical simulation model

Well spacing [m]	coordinates of oil well (x,y)	coordinates of water well (x,y)
125	(2,2)	(20,20)
150	(2,2)	(23,23)
175	(2,2)	(27,27)
200	(2,2)	(30,30)
225	(2,2)	(34,34)
250	(2,2)	(37,37)
275	(2,2)	(41,41)
300	(2,2)	(44,44)
325	(2,2)	(48,48)
350	(2,2)	(51,51)

The average value such as permeability, thickness, porosity, water saturation of each layer is set as the corresponding value of Numerical simulation model. Analyze the actual mining condition of each layer, and then according to the actual water injection intensity and liquid producing intensity, determine respectively the water injection and liquid producing capacity of the numerical simulation model, which is shown in Table 2.

Table 2 the parameter list of numerical simulation model

Layer	porosity [%]	Permeability[mD]	Water saturation [%]	Thickness [m]	Injection capacity per day [m <sup>3</sup> /d]	Liquid output per day [m <sup>3</sup> /d]
Group lower MHZ	28	1627	29	2.5	12.2	12.2
Group Upper GT	27	1555	32	2.5	23.6	23.6
group lower GT	23	936	33	2	10.9	10.9

According to the characteristic of oil viscosity and permeability from group lower MHZ, group upper GT and group lower GT, draw respectively permeability ratio curve of every layer, which is shown in Fig. 2.

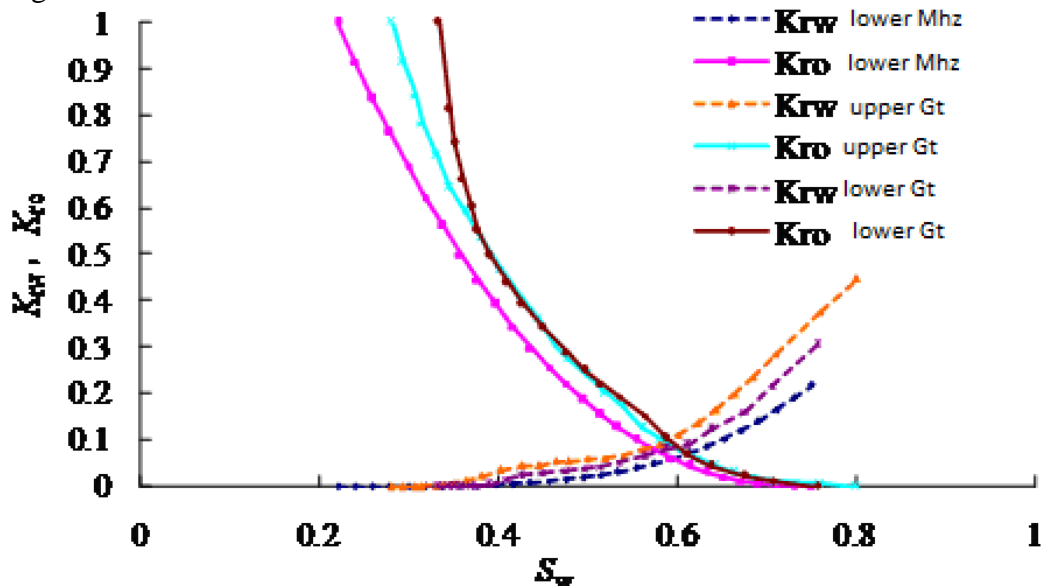


Fig. 2 permeability ratio curve of every layer

**Forecast result.** By the calculation of the above model, under the same scheme (which refers the same type reservoir), the time to achieve ultimate recovery degree is different, which could be seen in Table 3. And the relationship between recovery degree and time with different interval and different well spacing is drawn respectively, which is shown from Fig. 3 to Fig. 5.

Table 3 the calculating results of numerical simulation model

layer	Well spacing [m]	Ultimate recovery [%]	Production age limit [year]
group MHZ	125	35.88	4.16
	150	35.94	5.35
	175	36.04	7.21
	200	36.11	9.25
	225	36.19	11.80
	250	36.18	13.13
	275	36.24	16.88
	300	36.27	19.37
	325	36.28	22.87

layer	Well spacing [m]	Ultimate recovery [%]	Production age limit [year]
	350	36.30	25.79
group upper GT	125	49.07	2.22
	150	49.07	2.47
	175	49.11	3.73
	200	49.19	4.58
	225	49.21	5.77
	250	49.27	6.79
	275	49.30	8.23
	300	49.32	9.42
	325	49.33	11.12
	350	49.37	12.55
Group lower GT	125	51.36	2.97
	150	51.46	3.82
	175	51.60	5.18
	200	51.64	6.28
	225	51.70	7.98
	250	51.77	9.42
	275	51.80	11.46
	300	51.82	13.13
	325	51.85	15.55
	350	51.86	17.47

It can be seen from the table that in the same interval, the value of ultimate recovery degree is alike with different well spacing, but the production age limits has big differences. It costs shorter time to achieve ultimate recovery degree when well spacing gets smaller.

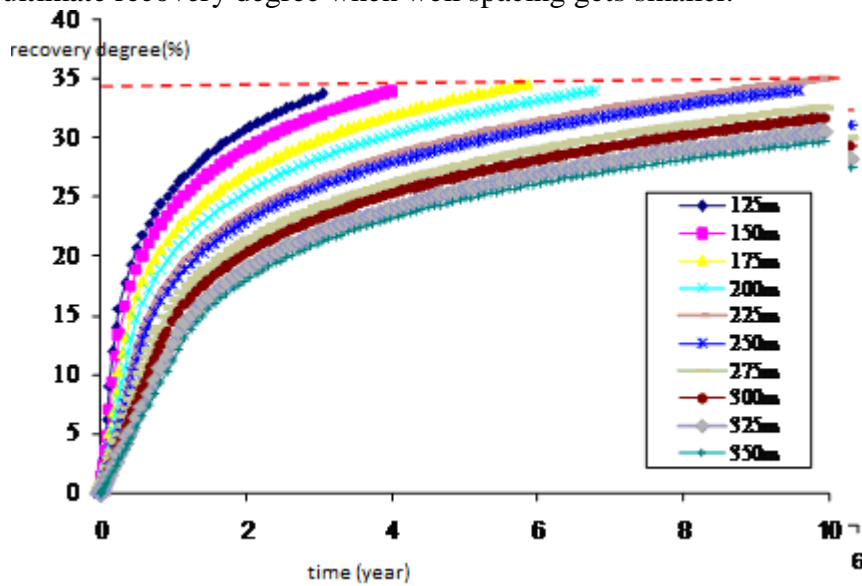


Fig. 3 the relationship between recovery degree and time with different well spacing on the lower MHZ

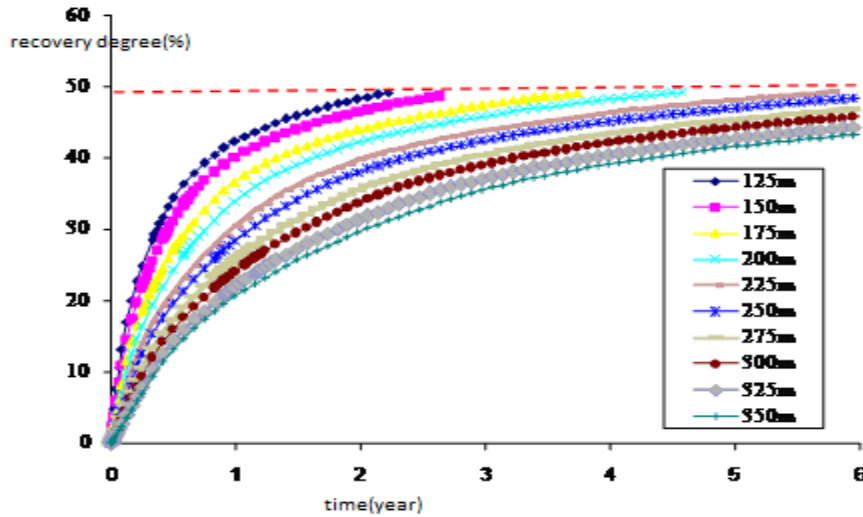


Fig. 4 the relationship between recovery degree and time with different well spacing on the group upper GT

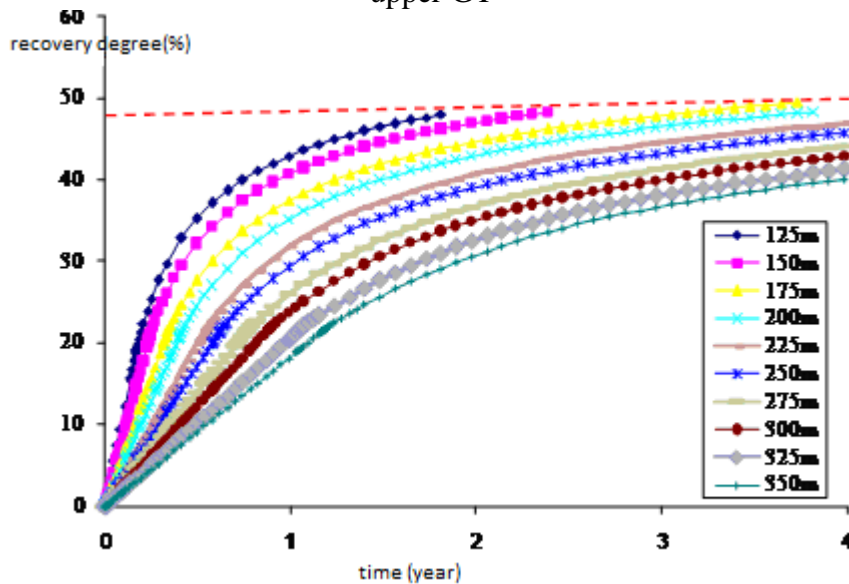


Fig. 5 the relationship between recovery degree and time with different well spacing on the group lower GT

From the relationship curve between recovery degree and time, it can be seen that with the increase of well spacing, recovery degree increase with the increase of time, and later the amplitude which recovery degree increased decreases. But the smaller well spacing, the shorter fixed time to reach the maximum recovery degree. But we can not determine the scope of the reasonable well spacing.

**Determine pseudo oil production rate.** In order to determine reasonable well spacing scope of each reservoir, guide the adjustment of oilfield later stage layer system and well pattern, improve oilfield development effect, the concept of pseudo oil production rate is introduced. Because the actual block is not a simple and ideal situation which a injection well is corresponding to a production well, the actual area is certain, the change of well spacing can lead to the change of the well number on unit area, which also refers the change of well spacing density. It can be seen in Fig. 6 and Fig. 7.

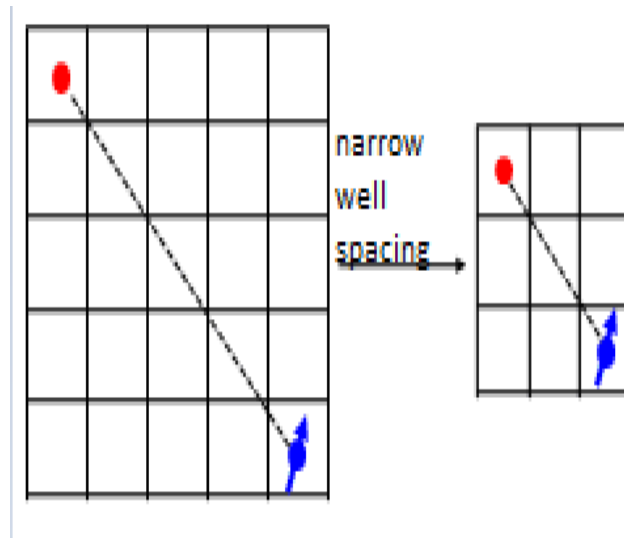


Fig. 6 reduce the spacing of the numerical simulation model

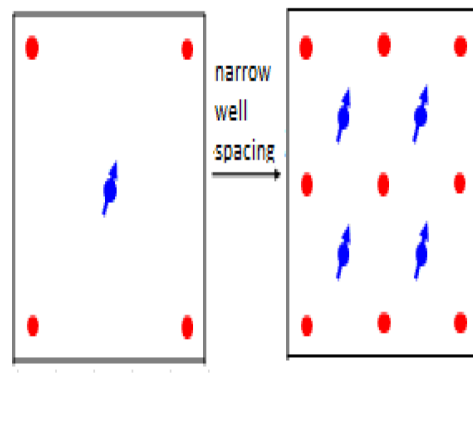


Fig. 7 reduce the spacing of the actual reservoir

In order to have comparability in the mining condition of different well spacing for Numerical simulation model, average annual oil production rate under different well spacing in the numerical simulation model is equivalent to the annual oil production rate from Wells unit area. Annual oil production rate from Wells unit area is called to pseudo oil production rate. The specific calculation method is as follows:

$$\text{pseudo oil production rate} = \text{average annual oil production rate per well} \times \frac{1}{(\text{well spacing}/100)^2} \times 100\% \quad (1)$$

Among them:

$$\text{Average annual oil production rate per well} = \frac{\text{recovery}}{\text{time}(\text{year})} \quad (2)$$

$$\text{The sum of well unit area} = \frac{1}{(\text{well spacing}/100)^2} \quad (3)$$

**The reasonable well spacing scope of every layers for PL oilfield.** According to the calculation results of numerical simulation model, combined with the definition of pseudo oil production rate, draw the relationship curve of every oil layer between pseudo oil production rate

and well spacing, which is shown in Fig. 8. The oil layer will correspond to different scope of reasonable well spacing under different pseudo production rate. According to the actual injection-production condition of PL oilfield, determine the actual oil production rate is about 1.1%, oil production rate is small. In order to adjust the development effect of later stage later stage, the scope of the reasonable spacing of different reservoir under the condition that pseudo production rate was 2% is determined.

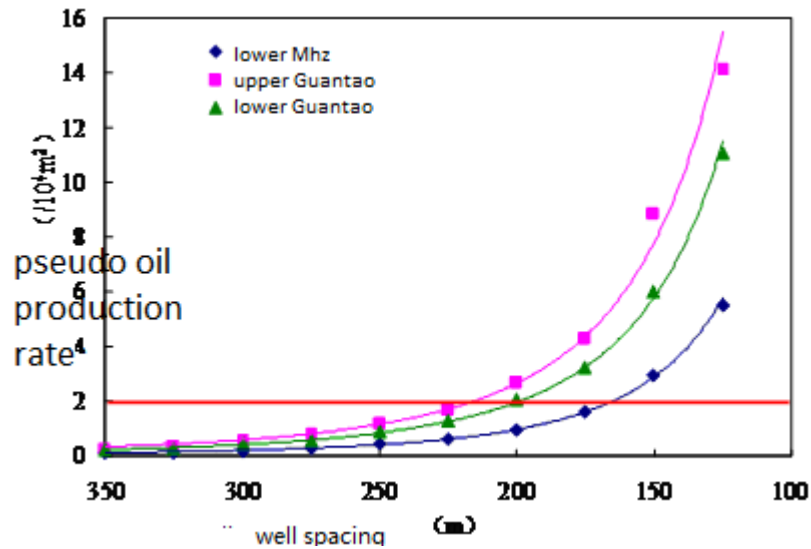


Fig. 8 pseudo oil production rate with different well spacing from different layers

It can be seen from the diagram that with the decrease of well spacing, pseudo oil production rate increases and the increased amplitude increased, which the increased amplitude of group GT increased greatest. When the pseudo oil production rate is 2%, the well spacing from group lower MHZ is about 160m, its reasonable well spacing range is from 150m to 200m. The well spacing from group upper GT is about 210m, its reasonable well spacing range is from 200m to 250m. The well spacing from group lower GT is about 200m, its reasonable well spacing range is from 175m to 225m.

Thus it can be seen that the well spacing range of the bottom of group MHZ is less than that of group GT. This is because that the group MHZ has a large crude oil viscosity, oil/water viscosity ratio is large, in order to improve the degree of washing, increase water injection sweep efficiency, it is essential to narrow well spacing. And group lower GT and group upper GT do not have a big difference in crude oil viscosity. Due to the permeability of group lower GT is poor than that of group upper GT, fluid start-up pressure is higher, so we need to narrow well spacing. And the well spacing range of group lower GT is less than that of group upper GT.

By the curvilinear regression between pseudo oil production rate and well spacing from different layers, the regression formulas between pseudo oil production rate and well spacing from the different layers is shown in Table 4.

Table 4 the regression formula between pseudo oil production rate and well spacing with different layers

layer	the regression formula
Group lower MHZ	$y = 1 \times 10^9 x^{-3.75}$
Group upper GT	$y = 8 \times 10^8 x^{-3.74}$
Group lower GT	$y = 5 \times 10^8 x^{-3.79}$



Through the above analysis, the regression formula between pseudo oil production rate and well spacing can be shown as follow:

$$y = ax^{-\beta} \tag{4}$$

Where  $y$  is pseudo oil production rate,  $/10^4 m$ ,  $x$  is well spacing,  $m$ ,  $a$  is coefficient related to geological parameters and production status,  $\beta$  is coefficient related to geological parameters and production status.

So the scope of reasonable well spacing can be determined in the actual production rate through the above regression formula. It provides a simple and effective method and theoretical basis for the adjustment of reservoir development.

### Formation well pattern adjustment scheme and effect

On the basis of reasonable well spacing scope, consider the actual drilling conditions of oilfield and the cost, the AA strategy of formation well pattern adjustment for PL oilfield is determined, which is shown in Fig. 9.

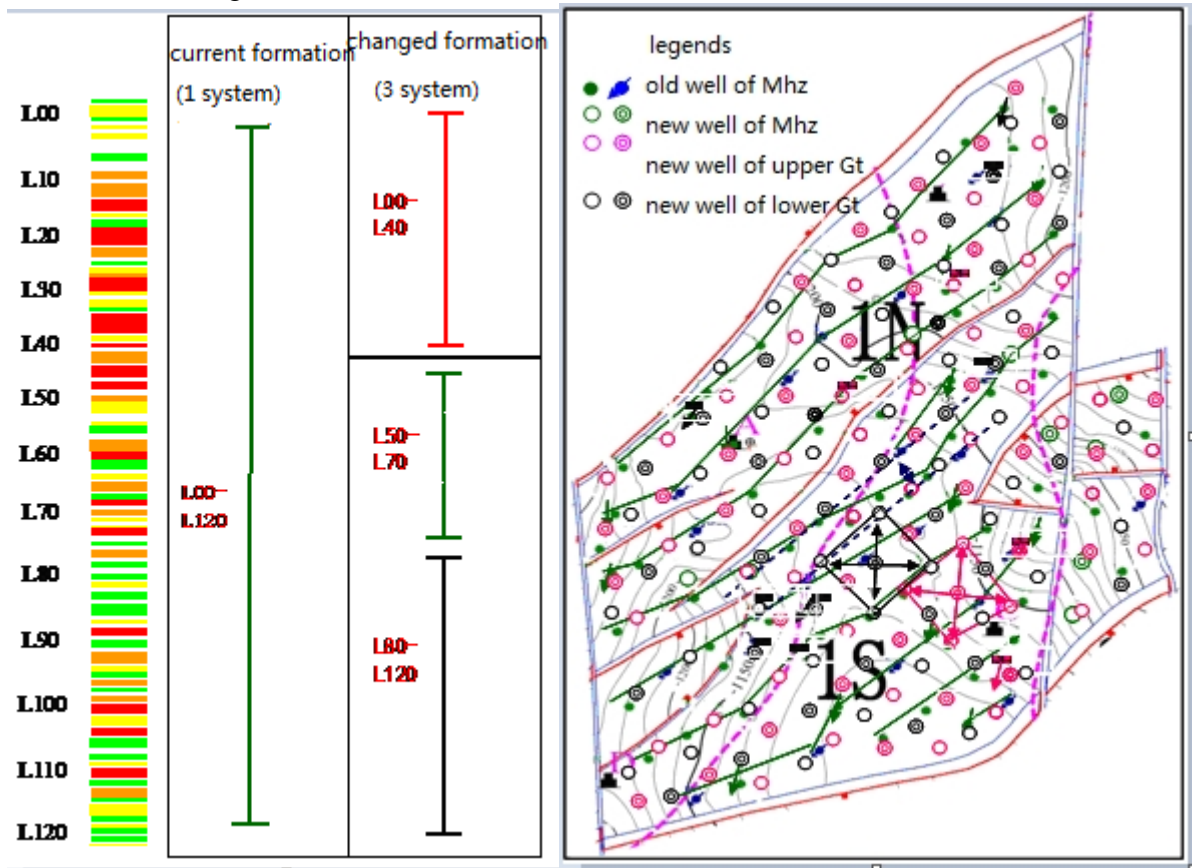


Fig. 9 the method of layer system combination and well pattern adjustment

The group MHZ and group GT are divided into three layer systems to do the synchronizing production, the specific design scheme is as follows: The layer system of group MHZ gives priority to new drilling, and combine with some old well, formed a set of five point area of 300m spacing pattern to develop. Group upper GT uses the old well to transfer the original area of the nine between well pattern of injection production Wells on the edge of the well, and drill some new Wells, and formed 300m spacing of transverse linear pattern mining. At the same time, the original Wells which perforated group MHZ and group lower GT is closed, group upper GT Is put into production. Group lower GT gives priority to new drilling, and combined with some old well,

formed a set of five point area of 300m spacing pattern to exploit group lower GT. The condition of production proration and injection proration from every layers is shown in Table 5.

Table 5 The condition of production proration and injection proration from every layers

Layer	The south area				The north area			
	injection rate per day		Liquid output per day		injection rate per day		Liquid output per day	
	Total [m <sup>3</sup> ]	Average per well [m <sup>3</sup> ]	total [m <sup>3</sup> ]	Average per well [m <sup>3</sup> ]	total [m <sup>3</sup> ]	Average per well [m <sup>3</sup> ]	total [m <sup>3</sup> ]	Average per well [m <sup>3</sup> ]
Group lower MHZ	403.32	16.13	403.32	14.40	262.42	17.49	262.42	17.49
Group upper GT	5331.62	242.35	5331.62	166.61	6010.83	500.90	6010.83	300.54
Group lower GT	10676.12	533.81	10676.12	395.41	10919.54	727.97	10919.54	606.64

The development effect forecast of formation well pattern adjustment scheme is completed, the result is shown in Fig. 10 and Fig. 11.

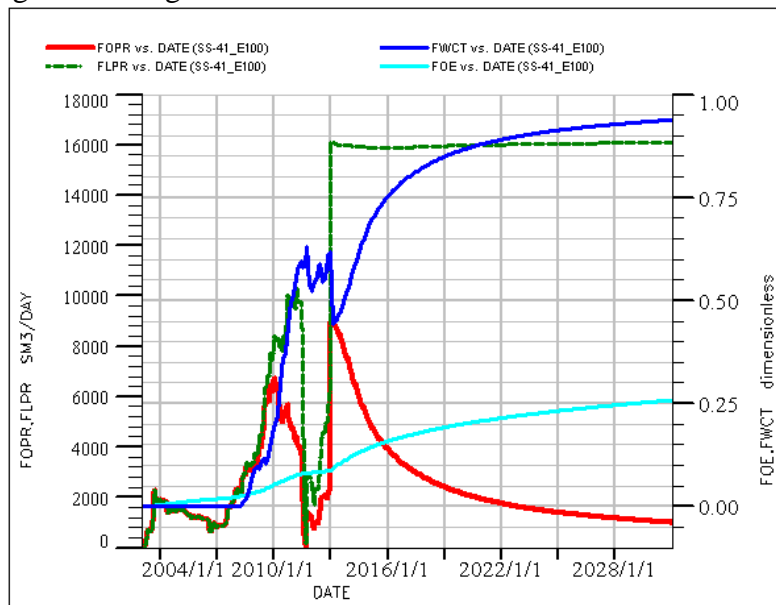


Fig. 10 the predicting curve of the south area

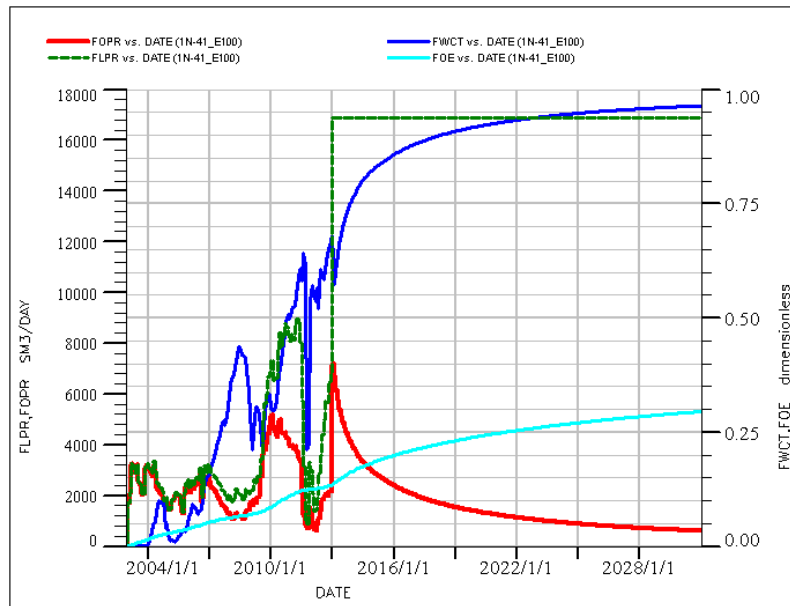


Fig. 11 the predicting curve of the north area

It can be seen from Fig. 10 and Fig. 11 that through constant liquid production, oil production declined year by year, it drops smaller at the late stage, the amplitude which recovery degree rises gradually becomes smaller, but the increased amplitude of the base plan is large. By the end of 2030, recovery degree of the south area is 26.3%, which is increased by 9.2% compared with the base plan, recovery degree of the north area was 29.5%, which is increased by 5.9% compared with the base plan.

To calculate the economic benefits under different drilling cost and the unit price of crude oil (economic benefit = the unit price of crude oil×recovery degree×crude oil reserves – the drilling costs), which is shown in Table 6. Scheme in the selection of single well cost and unit price of crude oil can be obtained certain economic benefits.

Table 6 Economic benefit calculation table

area	recovery degree[%]	Cost per well [ten thousand yuan]	Crude oil price [ten thousand yuan/m <sup>3</sup> ]	benefit [hundred million yuan]	oil increased output [ten thousand m <sup>3</sup> per well]
South area	26.3	10000	0.3	173.45	9.42
			0.6	441.89	
		5000	0.3	220.95	
			0.6	489.39	
North area	29.5	10000	0.3	52.97	6.23
			0.6	166.94	
		5000	0.3	83.47	
			0.6	197.44	

## Conclusions

(1) With the increase of well spacing, the recovery degree increases slowly over time. And it costs less time to reach the maximum recovery degree when well spacing becomes gets smaller.

(2) In order to determine the reasonable well spacing scope of different reservoir, the concept of pseudo oil production rate is introduced, which refers the average annual oil production rate per unit area. Different pseudo oil production rate is corresponding to different scope of reasonable well

spacing.

(3) According to the relationship curve between different well spacing and pseudo oil production rate, the reasonable well spacing scope of the reservoir in PL oilfield is calculated respectively when the pseudo oil production rate was 2%, group lower MHZ is from 150m to 200m, on the scope of reasonable well spacing for group upper GT is from 200m to 250m, group lower GT is from 175m to 225m.

(4) According to the scope of reasonable well spacing, determine the strategy of formation well pattern adjustment, predict the development effect by the numerical simulation model, finally it is concluded that recovery degree increased by 5.9%, the north and the south area of single well increase 94200m<sup>3</sup> per well and 62300m<sup>3</sup> per well respectively than before, it significantly improved the oilfield development effect.

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