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Strategy and Effectiveness of Development Adjustment Techniques on Complex Fractured Reservoir

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Abstract: *In view of the problems like low producing degree and prominent interlayer and areal contradictions appear during the process of water flooding development in fractured block D401 of Xinzhan oilfield, researches of fine fracture characterization，sedimentary microfacies subdivision and fine remaining oil by means of fine reservoir description have been performed to formulate personalized treatment according to the idea of partition adjustment. The block exhibits better development situation with water flooding control degree, water absorption ratio and fluid production proportion have been respectively enhanced by 6.5%, 8.6% and 8.9% after the implementation of indiscriminate infill, injection-production system adjustment, cyclic flooding, Subdivision and regroup, and the combination of the measures of 'adjustment，fracture and plugging' and super-short radius horizontal wells, which also provides reference for other fractured reservoirs.*
Key words: *fracture; personalized; indiscriminate infill; injection-production system adjustment; super-short radius; block D401*

I. Block Introduction

1.1 Geologic Characteristic

The ultra-low permeability reservoir of block D401 in Xinzhan oilfield located in the west of Daqing, which mainly develops Putaohua strata, has been explored in the end of the ninth five-year plan. The strata, an arch structure with steep wings and gentle shaft which belongs to Delta-front subfacies sediment [1], possess several features: buried depth of 1484～1715m, bearing area of 37.3km2, geological reserves of 571×10^4t, average porosity of 15.2%, average air permeability of 2.1mD, crude oil density of 0.746t/m3, viscosity of 1.8mPa·s. The primarily ingredient of clay mineral is illite, followed by kaolinite and chlorite. The initial formation pressure of 20.8MPa and saturation pressure of 11.3MPa indicates this block is abnormal high pressure reservoir. Meanwhile, Putaohua strata have the highest fracture developing frequency of 0.323n/m in west field according to the result of core observation and test [2]-[4].

1.2 Development Status

This block has been developed by means of invert nine-spot water flooding of 300m×300m since 1996. Constant pressure water injection and extensive profile control have been performed on the basis of the main development problems from 2003 to 2006. The implementation of indiscriminate infill, injection-production system adjustment and other comprehensive treatments help to relieve decline rate since 2011. By the end of 2014, this block possesses producing wells of 146 which has daily oil production rate of 58t，accumulated oil production rate of 83.78×104t，annual average water cut of 57.40% and recovery percent of 14.67%. It also has injection wells of 52 which has daily water injection rate of 889m3, accumulated water injection rate of 398.09×104m3 and accumulated injection-production ratio of 2.22.

II. The Primarily Development Problems

Block D401 presents followed contradictions after water flooding for more than ten years:

(1) The uneven producing of reserve derived from the great difference of water flooding control degree in each stratum. From the perspective of connectivity degree, the strata exhibits great difference with the worst one in PI7 (53%), and the best in PI1-1 (91.8%), and the multidirectional connected thickness ratios in each stratum are all under 23%. While the producing degree ranges from 36.3% to 76.7% with average value of 57.8%, and the fluid production degree rages form 49.5% to97.7% with average value of 71.3%.

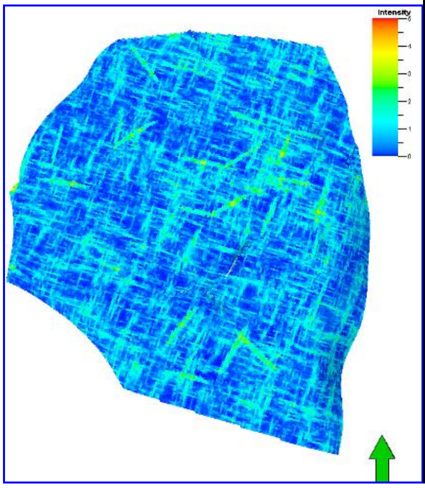
(2) The prominent interlayer and areal contradictions derived from multidirectional complex fracture lead to worse water flooding adjustment effect. The fine fracture research indicates that the high development and complex direction of fracture in this whole block result in the rapid water content rise, high fluid production with daily fluid production per well of 4.3t, and the enrichment of remaining oil on both sides of fracture. The poor effective water flooding production wells on the non-fracture direction result in large decreasing of reservoir pressure, low water content, and low fluid production with daily fluid production per well of 1.2t. In some well groups, ineffective water flooding still occurs in low water content wells even the high water content

wells have been shut in and the water injection intensity has been improved, which indicates huge remaining recoverable reserves exist on both sides of fracture and around ineffective wells.

III. Exploration Adjustment Technology

3.1 Fine Fracture Characterization

In consideration of the influence on development from fracture, the stratum fracture comprehensive description technology, which can be simply described as “point, plane, system”, has been performed for the purpose of understanding of fracture spatial distribution, by means of three-dimensional geological modeling, and with the help of exploration dynamic correction. Point: core observation and log calculation have been utilized to describe fracture intensity of well point. Plane: the digitization of fracture direction has been realized under the constraints of deflection, well point and faults distance. System: the fracture intensity model which includes the information of well point and direction has been established by means of dynamic monitoring model. And on this basis the sensitivity parameters have been adjusted according to exploration dynamic, which help to modify the fracture model and improve the spatial characterization accuracy of fracture after they have been updated in the original fine geological grid. With this technology, the fracture development direction of every single well and stratum have been determined and the stereoscopic characterization of fracture in each sedimentation unit of this block has been accomplished.



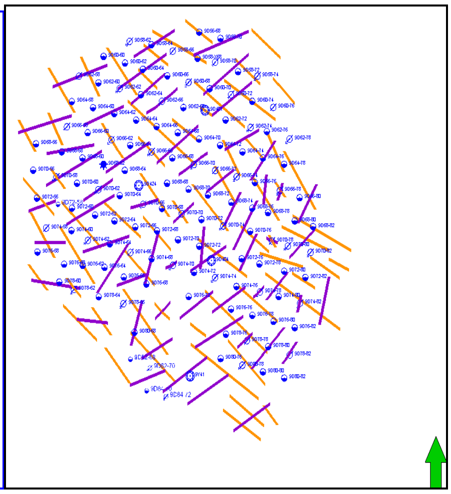


Fig 1 fracture development direction after extrapolation   Fig 2 fracture intensity model under multiple constraints

3.2 Sedimentary Microfacies Subdivision

The stratum sedimentary microfacies determines the trend and scale of single sand body and accurately describe the connection relationship, which provide the precise geological basis for tapping potential measures of fine water flooding like fracture breakthrough management and areal water channeling [5]. The application of information of core, seism, logging, and the former research of west region on Daqing placanticline proved block D401 is influenced by north and west provenance. Putaohua strata belongs to Delta-front subfacies sediment, which mainly develops delta inner front(including underwater distributary channel sandbodys, main shelf blanket sands, minor sand sheet, sand dam) and sheet sand of delta-frontal facies.

3.3 Fine Research Of Remaining Oil

3.3.1 Cause Of Remaining Oil

The remaining oil type of block D401 has been determined by means of the research result of fine reservoir description and numerical modeling combined with the production split and static and dynamic data, which include fracture interlayer contradiction, areal contradiction, poor effective water flooding, poor injection-production relationship and normal production. The first two types are the main tapping object which respectively account for 36.55% and 23.86% of remaining oil.

Table1 The remaining oil type of block D401

Couse of remaining oil	Conditions of residual recoverable reserves			recovery percent (%)
	residual recoverable reserves (10^4t)	ratio (%)	residual recoverable reserves of average well and single layer (10^4t)	
fracture interlayer contradiction	14.4	36.55	0.0949	11.12
areal contradiction	9.4	23.86	0.1157	9.18

poor effective water flooding	6.9	17.51	0.0737	9.34
normal production	6.5	16.50	0.0574	30.05
poor injection-production relationship	2.2	5.58	0.0339	8.54
Total	39.4	100.00	0.0752	12.51

3.3.2 Areal Distribution Law Of Remaining Oil

According to the comprehensive analysis of dynamic and static information on block D401, the areal remaining oil can be divided into these three following types: (1) Large area distribution. The well points closely grouped within the remaining oil area account for more than 40% in one stratum, which result from poor waterflooding, fracture inter layer contradiction, and fractured water breakthrough, and mainly distributes in layer PI4-2. (2) Part distribution. The ratio of this type ranges from 15% to 40%, which mainly distributes in layer PI1-1, PI1-2, PI2, PI3, PI5-1 and PI6-1 caused by areal contradiction and poor effective water flooding. (3) Scattered distribution. The ratio is less than 15% and form the stripped remaining oil within small area which mainly distributes in layer PI4-1, PI5-2, PI6-2 and PI7 caused by poor injection-production relationship and poor effective water flooding.

Table2 Areal remaining oil distribution of Block D401

type	Range of original effective thickness of single layer/m			original effective thickness		Conditions of residual recoverable reserves		Distribution layer
	≥1.0	0.5-1.0	0-0.5	total/m	ratio/%	residual recoverable reserves /10^4t	ratio/%	
Scattered distribution	51.3	66.1	23.0	140.4	22.53	10.3	26.1	PI4-1、PI5-2、PI6-2、PI7
Partly distribution	146.3	158.6	57.3	362.2	58.11	23.2	58.9	PI1-1、PI1-2、PI2、PI3、PI5-1、PI6-1
Large area distribution	72.6	41.2	6.9	120.7	19.36	5.9	15.0	PI4-2
Total	270.2	265.9	87.2	623.3	100	39.4	100	

3.3.3 Vertical Distribution Law Of Remaining Oil

The numerical modeling result indicates that remaining oil distribution is mainly influenced by fracture and nine-spot pattern and forms enrichment strip between well arrays. Oil saturation map shows that the layers PI1-1, PI1-2, PI2, PI3, PI4-2, PI5-1 and PI6-1 have the higher remaining reserves and should be considered as the main tapping object. The distribution of enrichment oil of the rest layers are all scattered.

3.4 Areal Adjustment Countermeasure

Block D401 has been divided into three districts according to development time and dynamic development characteristic and the personalized adjustment countermeasures have been manipulated. Cyclic flooding and scattered infill in enriched remaining oil area are introduced for old pilot area, scattered infill and injection-production system adjustment assisted with super-short radius horizontal wells for extended area, indiscriminate infill and injection-production system adjustment for other area.

Table3 Development adjustment countermeasure of block D401

Area	Development characteristics	adjustment countermeasure	Assisted measures
Old pilot area	Early developed, strong fracture development, high recovery percent, high water content, high injection pressure	Cyclic flooding and scattered infill	subdivision water injection, fracture, plugging
Extended area	Quality of reservoir becomes worse, thin, poor effective water flooding, low production and rapid decline of single well	scattered infill, injection-production system adjustment and super-short radius horizontal wells	
others	prominent interlayer and areal contradictions, numerous of low efficient wells	indiscriminate infill and injection-production system adjustment	

3.4.1 Well Pattern Infilling And Injection-Production System Adjustment

By utilizing the result of fine reservoir description and referring to the numerical modeling result and the adjustment experience of similar block [6]-[10], There are four flexible ways of indiscriminate infill and injection-production system adjustment have been performed with the comprehensive consideration of remaining oil distribution characteristics, fracture and underwater distributary channel sandbodys distribution law and the production condition of surrounding wells: (1) In the strata of local EW direction fracture development and enriched remaining oil, 8 infilling wells and 3 linear conversion wells have been deployed in the lateral of fracture; (2) Process of infilling was not applied in the strata of fracture development and poor remaining oil; (3) Horizontal well infilling and 1 irregular conversion well have been introduced in the stratum without fracture and remaining oil enriched in the single layer; (4) 11 diagonal infilling wells and 3 five-point conversion wells have been deployed in the strata without fracture and remaining oil enriched in multiple layers.

3.4.2 Overall Cyclic Flooding To Perform The Imbibition Functions Of Fracture And Matrix

Overall cyclic flooding has been performed in old pilot area (high recovery percent, relatively centralized high water content wells and relatively stronger fracture development) since the gradually increased injection pressure and multi-layers and multi-directions water breakthrough occur after multi-round profile control. In view of the numerical modeling, oil recovery rate by cyclic flooding is higher than continued water flooding. 18 well-times of cyclic flooding of 6-mon cycle has been implemented which helped to decrease the water cut increasing rate and stabilize the feed flow of low water content wells. The daily oil production rate of surrounding high water content wells increased from 1.7t to 4.3t, and water content decreased from 98.4% to 92.9%. The daily oil production rate of low water content wells stabilize at 58.3t (original 57.6t), and water content slightly decreased from 32.4% to 30.8%.

3.5 Vertical Adjustment Countermeasure

For the fractured water flooded wells, who have single flooded layer and enriched remaining oil in substitutes, or poor water injection condition layers resulted from inter layer contradiction, the subdivision and section adjustment have been performed in surrounding injection wells to cease water flooding thin layers in which water channeling easily occurs according to barrier fracture development condition between sections in order to control water content and improve the producing degree of poor layers. The water absorption ratio increases from 52.4% to 64.4% and the average daily oil rate per well of surrounding connected producing wells increases 0.5t after 21 well-times adjustment have been implemented. In addition, the utilization factor of water injection has been promoted and decline rate has been relieved by means of 42 well-times test adjustment to limit the injection of high flooded layer and increase the injection of low one, by which the average daily oil rate per well of surrounding oil wells increases 4.2t and the water content decreases from 52.5% to 49.8%.

3.6 Fracturing, Plugging And Super-Short Radius Horizontal Wells Technology

The prominent areal and interlayer contradictions exist in wells and layers have been adjusted by means of thin-poor layer fracturing, fractured flooded layer plugging and sidetracking super-short radius horizontal wells. (1) With the fine reservoir description result, the layers which have enriched remaining oil and poor effective water flooding resulted from fracture interlayer interference have been fractured to expand water flooding swept area. (2) For the multi-layers and multi-directions water breakthrough wells which possess ineffective injection adjustment, enriched remaining oil and plugging potential, the plugging scheme has been optimized to plug the upper and lower layers with barrier combined with the single layer fracture identification results. (3) Sidetracking super-short radius horizontal well technology has been introduced to tap the potential remaining oil from the wells and layers which possess the character of single large thickness layer, great physical characteristics, enriched remaining oil, sufficient water flooding energy, and easy water breakthrough after fracturing or approaching the fault. Above measures have been implemented in 20 wells which increased average daily oil production by 1.5t in initial stage after stimulation.(Table 4)

Table4 Classification statistics of stimulated wells

Stimulation type	wells /NO	before			after			Average accumulate oil increasing per well /t
		Daily fluid Production/t•d-1	Daily oil Production / t•d-1	Water content /%	Daily fluid Production /t•d-1	Daily oil Production / t•d-1	Water content /%	
plugging	6	41.1	0.5	98.8	18.0	8.4	53.2	81
fracturing	9	14.1	8.5	39.7	40.0	22.9	42.8	206
Plug-frac	1	2.6	0.0	100.0	2.5	1.9	24.0	205
super-short radius	4	6.5	6.0	8.1	17.4	11.1	35.9	170
total	20	64.3	15.0	76.7	77.8	44.3	43.0	161

IV. Development Adjustment Result

The production condition has been improved after implementing comprehensive tapping potential. The water flooding control degree increased 6.5 points from 72.8% to 79.3%. The water absorption ratio increased from 68.2% to 76.8%, fluid production ratio increased from 71.3% to 79.2%. The actual recovery ratio varied between 30% and 35% of theoretical value before comprehensive tapping potential while approaching 35% after adjustment which indicates that these measures help to obtain great effect.

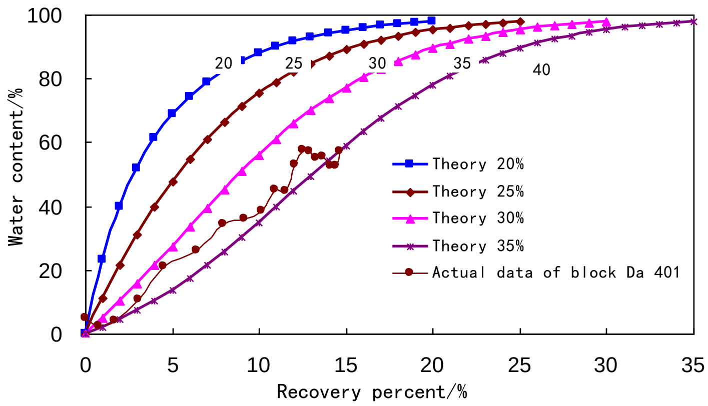


Fig3 Relationship curve of water content and recovery percent

V. Conclusion

(1) The personalized adjustment countermeasures have to be manipulated according to the actual conditions of fracture development, rapid water breakthrough and remaining oil enrichment in lateral of fracture because of the particularity of development and adjustment of complex fractured reservoir.

(2) Researches of fine fracture characterization, sedimentary microfacies subdivision and fine remaining oil by means of fine reservoir description could provide reliable evidence for block development and adjustment.

(3) With comprehensive consideration of the distribution law of remaining oil, fracture and channel sandbodys, the countermeasures including indiscriminate infill, injection-production system adjustment, cyclic flooding, Subdivision and regroup, combined with the measures of ‘adjustment， fracture and plugging’ and super-short radius horizontal wells can effectively relieve areal and inter layer contradictions and improve the block development effect.

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