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Experimental Study on Reservoir Sensitivity for Chang 6 Reservoir in CD Block of Ordos Basin

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Abstract

The development of low-porosity and low-permeability oil and gas fields has been concerned by scholars all over the world. This study focuses on the sensitivity study of Chang 6 reservoir in CD block of Ordos Basin. Through analysis by such technological means as rock core fluid flow experiment, X diffraction, rock core slices, scanning electron microscopy, it is proven that Chang 6 reservoir mainly gives primary to acid sensitivity, the velocity sensitivity is in the next place and the alkaline sensitivity and water sensitivity are in the end. The sensitivity minerals mainly cover the chlorite, calcite, ferrocalcite, dolomite, siderite and other minerals. Through discussion about the relationship among porosity, permeability and sensitivity indexes, it is deemed that he relationship among porosity, permeability and sensitivity indexes is closely related, and it is found through discussion for four kinds of sensitivity indexes that the trends of velocity sensitivity and acid sensitivity index curves are consistent, and the trends of alkali sensitivity and water sensitivity index curves are consistent. The consistency on relationship possibly enables that relationship between alkali sensitivity and water sensitivity are closely related to the fluid mineralization and the velocity sensitivity and acid sensitivity are closely related to the reaction rate of fluid.

Key words: Ordos basin; Chang 6 reservoir; Sensitivity mechanism; Reservoir protection; Sensitivity indexes

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INTRODUCTION

Coalbed methane (CBM) is a natural gas that gathers in poresand microfractures of coal seams (Karacan & Okandan, 2000). Oil and gas work the same way as coal-bed methane, are stored in pores and adsorbed rocks. Coalbed methane (CBM) compared with oil has the characteristics of strong heterogeneity (Moore, 2012; Pan, Connell, & Camilleri, 2010; Rachmat, Pramana, & Febriana, 2012), and the low porosity low permeability characteristics of ordos basin also have such characteristics, therefore, when drilling, when drilling into the reservoir, reservoir sensitivity caused by the expansion of the mineral, thereby damaging reservoir (Pillalamarry, Harpalani, & Liu, 2011; Kumar, Elsworth, Liu, Pone, & Mathews, 2012; Keim, Luxbacher, & Karmis, 2011; Peters, Walters, & Moldowan, 2005; Passey & Creaney, 1990). Among them, sensitivity is mainly caused by acid sensitivity, speed sensitivity, water sensitivity and alkali sensitivity (Bishop, 1997; Bennion, Thomas, & Bietz, 1996). Under complex geological conditions, these sensitivities can easily lead to collapse and leakage (Hatcher & Chen, 1996; Saulsberry, Schafer, & Schraufnagel, 1996; Valdya, & Fogler, 1992), affecting the development of oil and gas. Later in the process of secondary development, fracturing operation will also lead to change of reservoir pore and fracture, cause reservoir damage (Gale, Reed, & Holder, 2007), so the CD first discussed ordos basin block water sensitivity, acid sensitivity, alkali sensitivity and the relationship between velocity sensitive, reveals the relationship between four, help for the oil and gas exploration and development .At present, the research technology for low-yield and low-permeability oil field is deepening increasingly in our country, previous extensive-form mining mode has been changed and transferred as technology seeking and mode transferring as well as refined development mode of structure optimization. Since 1970s, the oil and gas reservoir damage and protection had been concerned doubly by numerous scholars in the petroleum industry (Deng, Li, Liang, & Zha, 2011). Reservoir damage means that, in the process of drilling, oil recovery and development, external fluid penetrates into the reservoir to change the porosity permeability of reservoir so as to reduce the porosity permeability. Reservoir sensitivity is usually studied by adopting both qualitative and quantitative methods. Qualitative study aims to the effect on reservoir damage by reservoir mineral types, and the quantitative study aims to the study on relationship between reservoir mineral content and permeability (Civan, 2007). This kind of functioning results are caused by capillary pressure change, swelling of clay minerals, stress change and permeability change (Shi & Durucan, 2004; Hassan, Rcza, Nazhat, & Ostojic, 2011). The practices of exploration and development have proved that the sensitivity is main factor limiting the exploration and mining of oil and gas, especially the sensitivity study is particularly crucial to the low permeability and extra-low permeability oil fields. The study for dense sandstone, coal-bed methane and shale is more critical (Jiang & Xie, 2005; Wang, Zhao, Liu, & Wang, 2006; Wei et al., 2008). The scholars at home and abroad has implemented the relevant exploration on relationship between sensitivity and clay minerals as well as sensitivity evaluation and prediction methods through sensitivity experiment study (Kang & Luo, 2000; Li & Yang, 2003; Peng, Yan, &Li, 1999; Zhou, Yao, & Chen, et al., 2007; Zhou, Yao, & Wang, et al., 2007; Zhao, Luo, & Yang, 2005).

To sum up, the predecessors focus on the single study on reservoir sensitivity and fail to carry out the study relationship among water sensitivity, velocity sensitivity, alkali sensitivity and acid sensitivity. Therefore, this paper analyzes and evaluates the sensitivity factors aiming to low permeability and extra-low permeability reservoirs in CD Block of Ordos Basin. The sensitivity of fluid velocity, sensitivity of acid sensitivity, sensitivity of alkali sensitivity and sensitivity of water sensitivity are comprehensively evaluated to provide the basis for oil and gas field development and reservoir protection, and the inherent correlation between them is discussed to expect to solve the related problems of the development and exploration of reservoir through discussing the relationship among four kinds of sensitivity.

1. GEOLOGICAL BACKGROUND

Ordos Basin is located at east longitude106°20′~110°30′and north latitude 35°~40°30′ and stretches across such five provinces and regions as Shaanxi, Gansu, Ningxia, Inner Mongolia and Shanxi. The tectonic location is located at the transitional zone in eastern part of China and western tectonic region. According to the history of ancient and modern construction and evolution, Ordos Basin can be divided into six first-order tectonic units. There is Northern Shaanxi (or Yishan) slope in the central section of basin, there is Jinxi flexure belt eastward; there is Tianhuan depression and thrust structural belt on western margin westward successively; there is Yimeng uplift in the north; there is Weibei uplift in the south(Figure 1). Under the control of Yanshan tectonic movement, the present tectonic appearance is characterized by tectonic framework that is low in the west and high in the east as well as high in the north and low in the south, with less stratigraphic dip, being less than 1°generally. The change of gradient for tectonics is gentle, showing obvious difference on ancient and modern tectonics pattern of in the east-west direction. This kind of tectonics difference is provided with direct influence on oil and gas generation and migration and accumulation (Zhao et al., 2005; Li, 2014; Cong, 2011; Feng, 2008).

2. CHARACTERISTICS OF CHANG 6 RESERVOIR

Through data analysis of drilling, rock core and detection logging, the Triassic System in Ordos Basin is divided into upper, middle and lower series, therein, upper triassic series are divided into five sections and 10 groups in detail from top to bottom, respectively including Chang group 1, Chang group 2, Chang group 3, Chang group 4+5, Chang group 6, Chang group 7, Chang group 8, Chang group 9 and Chang group 10. The characteristics of Chang 6 reservoir are analyzed respectively below.

2.1 Stratum Division and Sedimentary Facies

Lithology of Chang 1 reservoir: gray fine sandstone, off-white fine sandstone, green clay limestone, green argillaceous sandstone, dark gray mudstone, dark gray sandy mudstone, black mudstone, mottle mudstone interbedding, being sandwiched with multi-layer black carbonaceous shale, and thin coal seam, local coal seam can be exploited, containing abundant plant fossil fragments. Lithology of Chang2+3 reservoir: dark gray and mottle mudstone, dark gray sandy mudstone, light gray fine sandstone, light gray powder sandstone, light grey argillaceous sandstone. Lithology of Chang

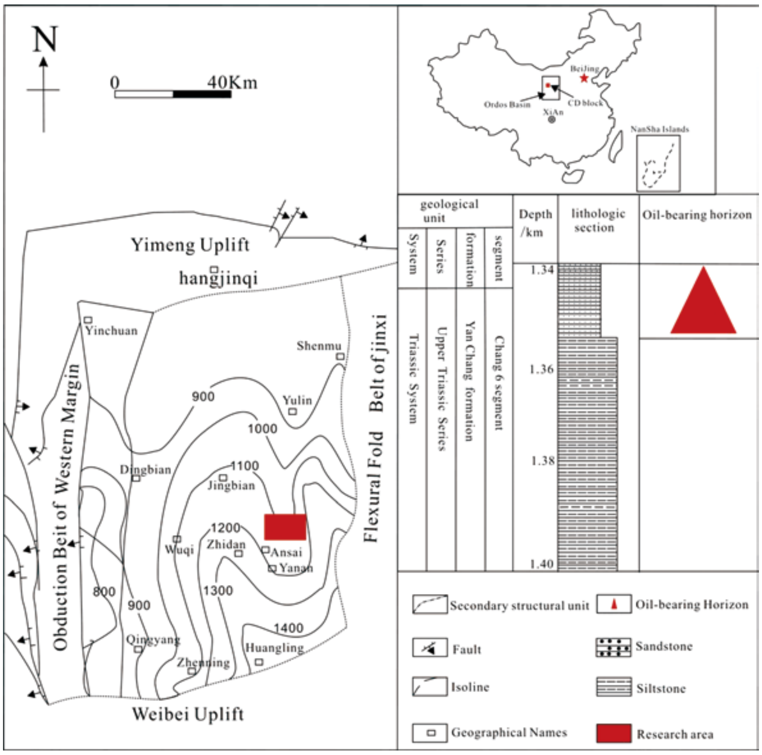


Figure 1
Structure Position of Study Area

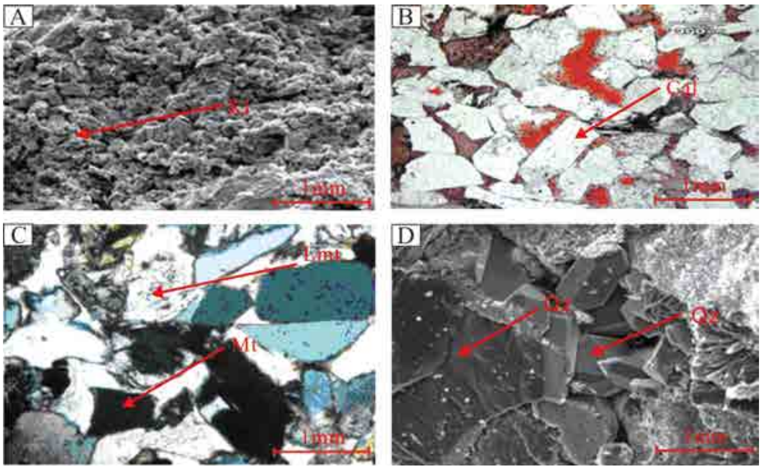
4 + 5 reservoir: sand mudstone interbedding gives primary to mudstone or carbonic mudstone. Lithology of Chang 6 reservoir: dark gray mudstone, dark gray sandy mudstone, light gray fine sandstone, light gray powder sandstone. Lithology of Chang 7 reservoir: sandy mudstone interbedding gives primary to black and dark gray shale. Lithology of Chang 8 reservoir: dark gray and gray black mudstone, dark gray sandy mudstone, light gray muddy sandstone and light gray fine sandstone. Lithology of Chang 9 reservoir: dark gray mudstone, light gray fine sandstone, grey argillaceous sandstone, black oil shale, dark gray sandy mudstone. Lithology of Chang 10 reservoir: dark gray mudstone, light gray fine sandstone, grey argillaceous sandstone, less dark gray sandy mudstone with greater sandstone thickness. River lake delta skirt system develops during Late Triassic Triassic epoch extension period. The study area is affected by the provenance in Northeast China to mainly develop as meandering river and meandering river delta deposition system. Initial depression development stage of the sedimentary lake basin for Chang10- Chang 8 reservoir; most prevailing stage of sedimentary lacustrine basin for Chang 7 reservoir; uplift stage sedimentary lake basin for Chang 6-Chang 3 oil reservoir group; uplift contraction stage of sedimentary lake basin for Chang 2-Chang 1 reservoir (Qi, Guo, Chu, Chen, & Zhang, 2013; Li, Pang, Cao, Xiao, & Wang, 2009).

2.2 Petrological Characteristics of Chang 6 Reservoir

In the study area, triassic system Chang 6 reservoir sandstone is characterized by fine particle size, good sorting, less impurity matrix and grain support. The grain contact relationship gives primary to mainly point-line and line contact, and the circular grinding degree gives primary to medium circular grinding. The particles are subangular. The skeleton component is high in feldspar content, with average content of 52. 7%; The content of quartz and detritus is low, and the average content is 24. 4% and 7.3% respectively. high content characteristics for this kind of unstable detrital components enable that the dissolution and authigenic mineral deposits in diagenesis develop very well. Clay minerals mainly cover the limonite, kaolinite, illite, siliceous and carbonate, and the content is 3.2%, 0.2%, 2.5%, 0.72% and 3.8% respectively. The average value of porosity is 9.4%, the average value of permeability is $1.39\times10^{-3}\mu m^2$, and the oil-bearing saturation is 1.8%. In general, Chang 6 reservoir belongs to feldspar sandstone type, with characteristics of low maturity is and moderate the structural maturity.

2.3 Type of Sensitive Minerals

The whole-rock mineral and relative clay mineral contents of the coal seam were determined by X-ray diffraction based on the Rietveld method (Ward, Taylor, Matulis, & Dale, 2001; Ruan & Ward, 2002). The fillings in Chang 6 reservoir are mainly composed of clay minerals and carbonate minerals, the siliceous minerals develop partially and are in different shapes and forms, becoming the main sensitive minerals in this reservoir. we selected 6 core samples in the extended oilfield test and analysis center: the average total content of clay minerals is 10.5%, the average content of chlorite is 3.2%, the average content of kaolinite is 0.2%, the average content of illite is 2.5% and the average content of siliceous rocks is 0. 78% through X-ray diffraction and electron microscope scanning. Chlorite: The content of chlorite in sandstone for Chang 6 oil reservoir group is 3.2%, the form mostly presents the thin film ring edge and attaches onto the periphery of the diagenetic mineral detritus and can't prevent quartz side enlarging, the spontaneous granular quartz is filled in the pores to grow in lamellar crystal, entering into the pore space and closing the micro-pores as well as playing a role in intergranule filling or rock debris metasomatism (Figure 2 D); Illite: autogenic illite is formed from the evolution of illite/smectite formation during mesozone rock stage, while illite presents pore liner or pore filling-type output in the accumulated sand body, seldomly occurring in Chang 6 reservoir of study area; Kaolinite: kaolinite mainly gives primary to intergranule filling, and the metasomatism is more common, and under electron microscope, the book-volume and wormlike glomerocryst output is presented (Figure 2 A). Carbonate cements are widely distributed in Chang 6 reservoir, mainly including calcite, ferrocalcite, dolomite, ferrodolomite and siderite. The development is characterized by ferrocalcite and dolomite, giving primary to spar carbonate and outputting in the form of poikilitic cementation, crystal stock cementation or mineral metasomatism. The muddy microcrystal carbonate is spot-shaped under the single polariscope, and under the electron microscope, there are out-of-order rhombohedral small euhedral crystals; The spar carbonate shows high-grade white interference color, and the crystals under electron microscope present the zyklopisch, and the rhombus cleavage is clear (Figure 2 B, C).



A: Chang 6 oil reservoir: the kaolinite is filled with intergranular pores, with good intercrystalline pore development.
B: Chang 6 oil reservoir: ferrocalcite with spot-like distribution during diagenetic later period.
C: Chang 6 laumontite presents crystal stock and is filled with most pores and metasomatic feldspar.
D: Chang 6 oil reservoir: The chloride thin film does not prevent the formation of the enlarged edge of quartz, and the authigenic granular quartz is filled in the pores.

Figure 2
Analysis on Thin Section for Chang 6 Reservoir in CD Area

3. SENSITIVITY EXPERIMENT METHOD OF CHANG 6 RESERVOIR

According to SY/ T5358-2010: *Petroleum and Natural Gas Industry Standard of People's Republic of China-Evaluation Method of Reservoir Sensitivity Flow Experiment* specification, the rock mineral characteristics and possible sensitivity hazard of Chang 6 reservoir are evaluated. The rock core sensitivity flow experiment is developed for reservoir, and the experiment evaluation is mainly implemented from such parameters as sensitivity of fluid velocity, sensitivity of fluid acid, sensitivity of fluid alkali and sensitivity of fluid water were evaluated.

3.1 Flow Velocity Sensitivity Experiment of Chang 6 Reservoir

Velocity sensitivity flow experiment principle: the formation water is injected into the rock core at different infusion speed (small to large), the permeability rate of rock core is measured out under different infusion speeds, the relation curve between the velocity and permeability rate is implemented through statistics, and the relation curve is utilized to judge the critical flow velocity (Du, 2012; Li, Guo, Guo, & Su, 2009) for rock core by utilizing the relation curve. The results of velocity sensitivity experiment show (as shown in Table 1) that the permeability damage rate of 3 samples is more than

50%, the velocity sensitivity index is greater than 0.5 and the degree of velocity sensitivity is medium and stronger; the permeability damage rate of other samples is less than 50%, the velocity sensitivity index is less than or equal to 0.5 and the degree of velocity sensitivity is weaker. It is observed totally that the degree of velocity sensitivity is medium velocity sensitivity.

Table 1
Velocity Sensitivity Data of Chang 6 Reservoir

Well No.	Gas Permeability Rate	Porosity	Critical Flow Velocity (m/day)	Damage Rate	Velocity Sensitivity Index	Degree
1	0.7	10.3	11.9	50.5	0.5	Medium velocity sensitivity
2	1.1	11.6	10	35.6	0.4	Medium weak
3	1.8	11.3	24.4	24.2	0.2	Weak velocity sensitivity
4	0.3	13.3	6.7	32.0	0.3	Medium weak
5	1.1	11.3	10.9	27.01	0.3	Weak velocity sensitivity
6	0.7	11.1	43.2	16.7	0.2	Weak velocity sensitivity

3.2 Acid Sensitivity Experiment of Chang 6 Reservoir

Acid sensitivity flow experiment principle: the permeability rate of formation water for rock sample before acid filling is served as the standard, HCl of 0.5 PV-1 PV (pore volume multiple) is filled, and then the formation water displacement (Du, 2012; Li et al., 2009) is carried out, and the degree of acid sensitivity is judged through the change value of formation water permeability rate before and after acid filling. The results of acid sensitivity experiment show that three rock samples are strong acid sensitivity, two rock samples are weak acid sensitivity and one rock sample is free of acid sensitivity. The rock sample permeability rate of strong acid sensitivity is relatively higher (as shown in Table 2). At present, it is observed that it is necessary to further study the mechanism or law of acid sensitivity for Chang 6 oil reservoir.

Table 2
Acid Sensitivity Data of Chang 6 Reservoir

Well No.	Gas Permeability Rate	Porosity	Permeability Rate of Formation Water	Name of Acid Fluid	PH Value of Acid Fluid	Acid Fluid Consumption (PV)	Permeability Rate of Formation Water	Acid Sensitivity Indexes	Acid Sensitivity Degree
1	0.72	9.7	0.315	HCl	5	1.46	0.057	0.82	Strong acid sensitivity
2	0.86	12.6	0.292	HCl	5	1.02	0.273	0.07	Weak acid sensitivity
3	1.10	11	0.293	HCl	5	1.1	0.051	0.83	Strong acid sensitivity
4	0.695	11.5	0.217	HCl	5	1.46	0.172	0.21	Strong acid sensitivity
5	0.258	12.4	0.023	HCl	5	1.03	0.022	0.04	No acid sensitivity
6	0.558	11.1	0.187	HCl	5	1.04	0.053	0.72	Strong acid sensitivity

3.3 Alkali Sensitivity Experiment of Chang 6 Reservoir

Alkali sensitivity experiment principle: Firstly, KC1 solution is prepared according to the total salinity of standard salt water (or formation water), and the pH value of this solution is used as the initial pH value. The pH value of KCl solution is adjusted by utilizing NaOH, and the pH value of the alkali liquor is increased according to the interval of 1. 5 pH values. 10-15 time PV of alkali solution that pH value has been prepared properly is filled into the rock core. This solution is utilized to measure the permeability rate of rock sample after static saturation for 12h (Du, 2012; Li et al., 2009). The experiment shows (shown in Table 3) that, the alkali sensitivity index of 6 rock samples is between 0.14 and 0.33, and the degree of alkali sensitivity is weak to moderate alkali sensitivity.

Table 3
Alkali Sensitivity Data of Chang 6 Reservoir

Well No.	Gas Permeability Rate	Porosity	Permeability Rate of Formation Water	Name of Alkali Fluid	PH Value of Alkali Fluid	Alkali Fluid Consumption (PV)	Permeability Rate of Alkali Fluid After Placing	Alkali Sensitivity Indexes	Alkali Sensitivity Degree
1	1.020	10.5	0.519	KOH	10	18.8	0.393	0.24	Weak acid sensitivity
2	0.918	11.8	0.430	KOH	10	16.5	0.349	0.19	Weak acid sensitivity
3	1.268	11.4	0.693	KOH	10	16.4	0.598	0.14	Weak acid sensitivity
4	0.281	12.9	0.029	KOH	10	15.9	0.022	0.24	Weak acid sensitivity
5	1.550	11.3	0.914	KOH	10	17.4	0.611	0.33	Medium weaker
6	1.232	12.3	0.603	KOH	10	16.2	0.441	0.27	Weak acid sensitivity

3.3 Water Sensitivity Experiment of Chang 6 Reservoir

Water-sensitivity experiment principle: Firstly, the formation water is utilized to flow through the rock core, and then the formation water that the mineralization degree is half of formation is utilized to flow through the rock core, the non-ionic water flow is utilized finally to flow through the rock core so that the quantitative influence on rock core permeability rate by three kinds of water with different salinity is determined respectively and the damage degree of water sensitivity by rock core is analyzed (Hassan et al., 2011; Jiang & Xie, 2005). The experiment results show that the water sensitivity test of reservoir is carried out by utilizing 6 rock samples and three rock samples are injected with 50% formation water and non-ionic water. The permeability rate is free of loss and water sensitivity. The water sensitivity index of three rock samples is 0.3-0.5, the water-sensitivity degree is medium and weaker water sensitivity, and the rest three rock samples are weak water sensitivity (shown in Table 4).

Table 4
Water Sensitivity of Chang 6 Reservoir

Well No.	Gas Permeability Rate	Porosity	Permeability Rate of Formation Water	Permeability Rate of 50% Formation Water	Permeability Rate of Non-ionic Water	Water Sensitivity Indexes	Water Sensitivity Degree
1	1.2	10.7	0.4812	0.481	0.434	0.1	Weak water sensitivity
2	1.022	12.1	0.481	0.473	0.463	0.04	No water sensitivity
3	1.675	11.2	0.939	0.715	0.886	0.06	Weak water sensitivity
4	0.348	13.7	0.112	0.069	0.074	0.34	Medium weaker
5	2.857	11.5	1.47	1.343	1.412	0.04	No water sensitivity
6	1.686	11.6	1.052	0.961	0.966	0.08	Weak water sensitivity

4. ANALYSIS AND EVALUATION ON SENSITIVITY DAMAGE MECHANISM FOR CHANG 6 RESERVOIR

Reservoir sensitivity means that the accumulated permeability and porosity change under the external action to produce certain influence on the reservoir. The influence includes positive and negative influences, the positive influence is favorable to the reservoir, increasing the porosity and permeability of reservoir; the negative influence is unfavorable to the reservoir, reducing the permeability rate of reservoir, the performance is just opposite on sensitivity index, the positive effect means that the index is negative value, and the negative effect means that the index is positive value. The analysis and evaluation for four kinds of sensitive mechanisms for Chang 6 reservoir in CD Block are described as follows:

4.1 Mechanism and Evaluation on Water Sensitivity for Chang 6 Reservoir

Fluid water sensitivity refers to the phenomenon that the liquid with different salinity enters into the reservoir to cause the clay expansion, migration and dispersion so that the pore duct diminishes, the permeability decreases and the reservoir is damaged. The main purpose is to search for the critical mineralization of the injected liquid and prepare the injected liquid with suitable mineralization. The experiment results show that the water sensitivity index range is 0.04 ~ 0.038. When the average value is

0.1, it is considered that the water sensitivity of Chang 6 reservoir reaches medium to weak water sensitivity, the content of expansive minerals in the reservoir is less and the damage degree of water sensitivity to the reservoir is little. Generally speaking, most clay minerals have certain expansibility, and the expansion capacity of montmorillonite is strongest, the Edmond or Malmmunite minerals rank second, the expansion capacity of chlorite and illite is weak, and the clay mineral kaolinite is free of expansion. Because clay minerals in Chang 6 reservoir of CD Block mainly cover chlorite, kaolinite, illite, siliceous and carbonate, with content of 3.2%, 0.2%, 2.5%, 0.78% and 3.8% respectively, therefore, the water sensitivity condition in the study area is weak.

4.2 Mechanism and Evaluation on Velocity Sensitivity for Chang 6 Reservoir

Velocity sensitivity refers to the phenomenon that, when the fluid enters into the reservoir for flowing, the change for velocity of fluid causes the moving and gathering of granules in the stored and concentrated duct and duct blocking so as to change the permeability of reservoir. The purpose of the experiment is to search for the critical velocity maximally injured by fluid flow and prepare the appropriate injected velocity fluid. The velocity sensitivity experiment results show that the critical velocity range of velocity sensitivity for Chang 6 reservoir is 6.86-437.16m/s, the average value is 17.86m/s, the velocity sensitivity index scope is 0.017-0.036 and the average value is 0.3. It can be observed from the scanning electron microscope photographs that the kaolinite particles in the pores stack in page shape. Because the velocity of the fluid can cause the particles to fall off and block the pores to cause that the permeability reduces, however, the content of kaolinite is 0.2% only, and low content causes insignificant particle falling off. The illite is thread strand shape and easily block the pores during the flow of fluid, but the content is low and is 2.5% only, so it is considered that Chang 6 reservoir is medium velocity sensitivity.

4.3 Mechanism and Evaluation on Acid Sensitivity for Chang 6 Reservoir

Acid sensitive refers to the phenomenon that the minerals with acidity sensitivity liquid react with acid fluid entering into the reservoir to produce the precipitated particles or colloid liquid so as to result in permeability decrease. The purpose of the acid sensitivity experiment is to search for the critical pH value injected into the acid liquor, determine the PH value of maximally harmed acid solution, optimize the acid solution and search for reasonable and effective acidizing treatment method. Reservoir acidification is one of the important stimulation measures in oil field development. The purpose of acidizing is to dissolve some soluble minerals in the pores by injecting the acid liquor so as to lead to acid-rock reaction and produce the chemical precipitation, gel or release the particles and block the pore duct as well as reduce the permeability, playing the counteraction. Through acid sensitivity experiment for Chang 6 reservoir in study area, it is found that acid sensitivity degree is different. There are three samples show strong acid sensitivity, with the acid sensitivity indexes of 0. 82, 0. 83, 0. 72; Block 2 shows weak acid sensitivity, with acid sensitivity indexes of 0.07 and 0.21; Block 1 is acid sensitivity-free, with acid-sensitivity index is 0.04. This kind of irregular acid sensitivity may be related to the mineral composition and content in different rock sample minerals. The content and type of acid-sensitive minerals lead to different distribution range of acid-sensitivity for Chang 6 reservoir in study area. For specific study, it is also necessary to implement a great deal of experimental analysis on the acid sensitivity for Chang 6 reservoir in CD block to obtain the isograms for distribution scope of acid sensitivity so as to better guide the practices. Chang 6 reservoir contains a large number of chlorites and carbonates, and the pore structure is micropore and fine throat. When hydrochloric acid is injected, the hydrochloric acid mainly reacts with chlorite and lomonite to form the sediments and plug the throat so as to decrease the permeability. The reaction mechanism is as follows:

$$Fe^{2+} + OH^{-} \xrightarrow{\qquad\qquad} Fe(OH)_2\downarrow$$

4.4 Mechanism and Evaluation on Alkali Sensitivity for Chang 6 Reservoir

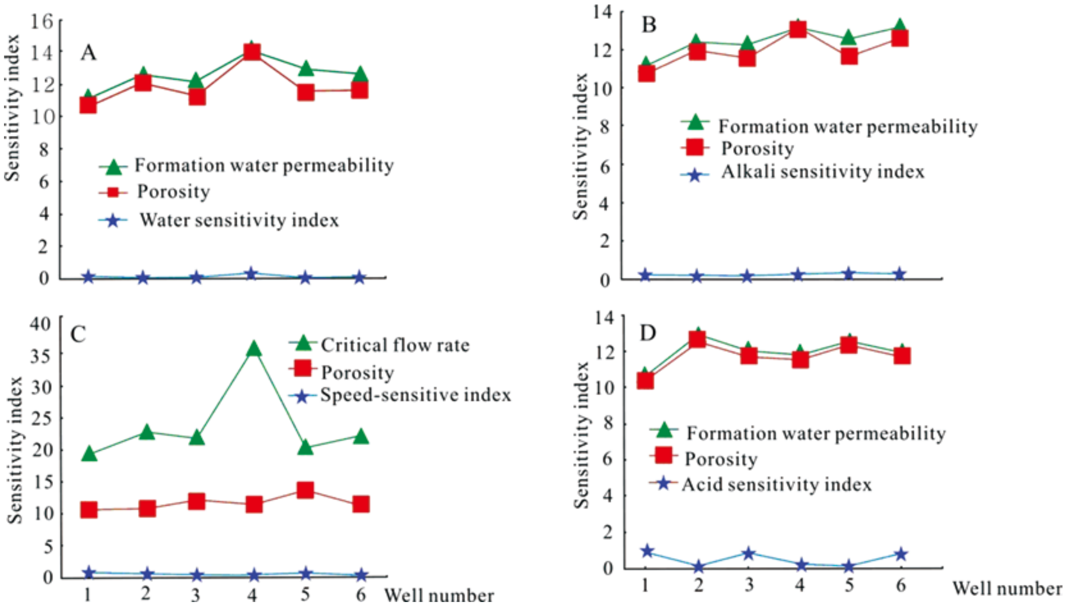
Alkali sensitivity refers to the phenomenon that the alkali working fluid that PH value of fluid is greater than 7 in the reservoir reacts with rock or formation fluid to lead to the decrease of pore throat permeability. The purpose of the experiment is to search for reasonable PH value of alkali liquid injected into the reservoir and reduce the damage to the reservoir. The range of alkali sensitivity index of Chang 6 reservoir in CD Block is 0.14-0.33, with average value of 0.19, which is moderately weak alkali sensitivity to weak alkali sensitivity. Because rock sample minerals are mainly composed of chlorite, kaolinite, illite, siliceous and carbonate (dolomite, calcite and zeolite), the reaction activity of chlorite and quartz is moderate, so the degree of alkali sensitivity is moderately weak to weak.

5. CORRELATION DISCUSSION FOR FOUR KINDS OF SENSITIVITY INDEXES IN CHANG 6 RESERVOIR

Reservoir sensitivity study is of great significance to oil and gas exploration and development and reservoir protection. The correlation of reservoir sensitivity is discussed in two portions below:

5.1 Discussion on Relationship Among Sensitivity, Porosity and Permeability

(a) Chang 6 reservoir is weak water sensitivity to no water sensitivity basically, and the permeability and porosity are basically unchanged by injecting 50% formation water and non-ionic formation water, showing that the degree of mineralization for injected water fails to damage the porosity permeability of the reservoir and the water sensitivity index curve is almost horizontal (Figure 3-a); no matter what kind of water with degree of mineralization is injected, the porosity and permeability curve is basically consistent, and there isn’t any relation with water sensitivity index curve; the greater the porosity and permeability, the stronger the water sensitivity. (b) Chang 6 reservoir is weak alkali sensitivity basically, and only one sample is medium alkali sensitivity. By injecting the alkali liquid with 10 PH value, it is found that the reservoir of Chang 6 reservoir in this area gives primary to weak alkali sensitivity basically, the permeability change of the reservoir is basically consistent with the condition that the alkali liquid isn’t injected, the basic retention level of alkali-sensitivity index curve is basically independent of porosity permeability curve (Figure 3-b), and the porosity is consistent with the permeability, the higher the porosity, the higher the permeability. (c) Chang 6 reservoir gives primary to medium velocity sensitivity, the smaller the porosity, the higher the critical velocity of the velocity sensitivity. This kind of condition may be: the smaller the porosity, the faster the flow velocity of the fluid in the pores, the greater the impact force of the fluid to the rock inside the pores, which may cause that unstable loose mineral particles tend to fall off and are carried out to result in higher critical speed for occurrence of velocity sensitivity. (Figure 3-c). (d) The acid sensitivity of Chang 6 reservoir is strong but the regularity is not obvious. The sensitivity of acid sensitivity for Chang 6 reservoir in different well locations is provided with obvious difference, and acid-free sensitivity-medium acid sensitivity-strong acid sensitivity exists concurrently, which is main characteristic of Chang 6 reservoir in this study area. It is found that the trend of porosity and permeability curve is basically consistent but is different from obvious trend of acid sensitivity index curve. It can be observed from (Figure 3-d) that, the smaller the porosity permeability value, the stronger the acid sensitivity, the greater the pore permeability value, the weaker the sensitivity of acid sensitivity, the sensitivity for this kind of acid sensitivity is likely to be related to the flow rate of acid liquid in pores. Generally speaking, under equal conditions, the permeability and porosity are less, the flowing velocity of fluid under equal pressure is fast, the reaction time occurred between acid liquid and the rock minerals is less, the generated precipitation is less, therefore, the sensitivity of acid sensitivity is weak, vice versa.



A: Relationship between Water Sensitivity Indexes and Porosity Permeability.
B: Relationship between Alkali Sensitivity Indexes and Porosity Permeability.
C: Relationship between Velocity Sensitivity Indexes and Porosity Permeability.
D: Relationship between Acid Sensitivity Indexes and Porosity Permeability.

Figure 3
Relationship Between Porosity Permeability and Four Kinds Sensitivities

5.2 Relationship among Four Kinds of Sensitivities

Through correlation study for velocity sensitivity index, acid sensitivity index, alkali sensitivity index and water sensitivity index for Chang 6 reservoir in CD Block, the curve trend of velocity sensitivity indexes and the acid sensitivity indexes is consistent, and only the numerical value is different. The value of the speed-sensitive index curve is always greater than that of the acid-sensitive curve, and the slope of two curves is basically consistent (shown in Figure 4). The alkali-sensitivity index curve and the water-sensitive index curve are consistent basically in trend, and the numerical value is different, the slope of the two curves is basically consistent. The velocity sensitivity index curve, the acid sensitivity index curve and the alkali sensitivity index curve are obviously different from the water sensitivity index curve, this kind of difference may show that the velocity sensitivity and the acid sensitivity are related to the reaction time of fluid in the pores, and the alkali sensitivity and water sensitivity are closely related to fluid mineralization.

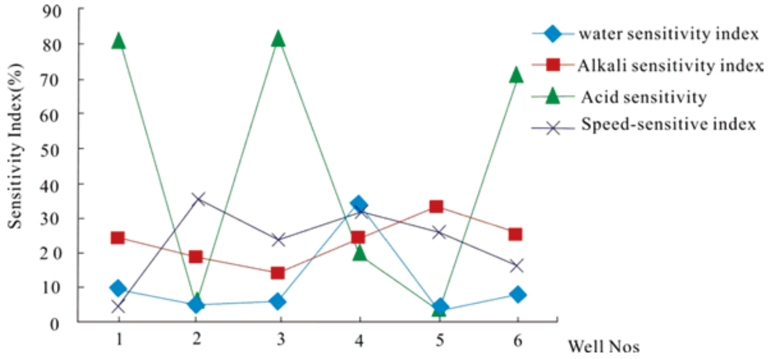


Figure 4
Relationship Diagram for Four Kinds of Sensitivities

CONCLUSIONS

Through sensitivity study for Chang 6 reservoir in CD block of Ordos Basin, it is found that:

(a) Chang 6 reservoir belongs to feldspathic sandstone type with low compositional maturity and medium structural maturity, giving primary to siltstone mainly; the mineral compositions give primary to clay minerals and carbonate rocks mainly.

(b)The sensitivity study results of Chang 6 reservoir show that strong acid sensitivity is dominated, but the acid sensitivity distribution is regular, it is required to perform a large area of experimental analysis and study. Therefore, it is important to pay attention to allocate the reasonable acidification liquid in future acidizing treatment.

(c) The relationship discussion among sensitivity, porosity and permeability for Chang 6 reservoir shows that sensitivity is not only related to the type of minerals but also related to porosity and permeability. The velocity sensitivity and acid sensitivity are closely related on reaction rate and residence time of fluid. The water sensitivity and alkali sensitivity are closely related to the degree mineralization for fluid injected into the reservoir.

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