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Characteristics of Shale Gas Reservoir in Jiyang Depression and its Significance in Drilling and Exploitation

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A B S T R A C T

Physical and geochemical characteristics of shale play conclusive role in confirming operation measures during drilling and stimulation. The properties of shale samples from Jiyang depression were investigated through X-ray diffraction, scanning electron microscope, adsorption isothermal, high pressure mercury intrusion, methylene blue trihydrate, pressure pulse decay, tests of specific water wettability and shale stability index. Correlations, geological and engineering significances of them were discussed. Results show that shale reservoir in Jiyang depression has exploitation value corroborated by good characteristic parameters: 2.86% TOC, 69.9% brittle mineral, 26.14% clay mineral, high permeability of $0.011 \times 10^{-3}\mu m^2$, large Langmuir volume ($5.82\ cm^3/g$) and Langmuir specific area ($0.91\ m^2/g$), effective porosity (3.77%) and thickness (130.66m). Langmuir specific area is the key control on methane adsorption and storage verified by its moderate positive relativity with Langmuir volumes rather than TOC. High illite content (69.29%) may lead to instability of borehole and velocity sensitivity damage. Microfractures provide channels for filtration, invasion and loss of drilling fluid. Large specific water wettability ($4.36 \times 10^{-7} g/m^2$) and smaller shale stability index (19.99 mm) dispalyed that shale formation were unstable once contacting with fresh water. Countermeasures must be adopted during drilling and fracturing to reduce reservoir damage and complex downhole conditions.

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NOMENCLATURE

API	American Petroleum Institute	H_i	Needle penetration of shale before water sucking (mm)
CEC	Cation exchange capacities	ΔH	Swelling capacity of shale (mm)
HPMI	High pressure mercury intrusion	S_w	Specific water wettability of shale ($10^{-7}g/m^2$)
I/S	Mixed-layer of illite and smectite	w_2	Weight of shale power after water sucking (g)
MBT	Methylene blue trihydrate	w_1	Weight of shale power oven dried 5 hours under 105℃ before water sucking (g)
NA	Nitrogen adsorption	w_0	Weight of container (g)
P_L	Langmuir pressure	S_s	Specific surface area of shale powder (m^2/g)
SEM	Scanning electron microscope	x_i, y_i	i=1,2,3,…n
SSI	Shale stability indexes	$\bar{x}$,$\bar{y}$	Averages of being analysed variables
TOC	Total organic carbon	r	Pearson product-moment correlation coefficient
V_L	Langmuir volume	**Subscripts**	
XRD	X-ray diffraction analysis	*w*	Water
T	Temperature	*s*	Shale powder
H_f	Needle penetration of shale after water sucking (mm)		

1. INTRODUCTION

With the development of horizontal drilling technology, segregated fracturing technology and the increase of global energy demand, more and more attentions were paid on shale gas exploration and exploitation. Results of geological prospect show that shale gas reservoir may mainly distribute in Sichuan, Ordos, Bohai Gulf,

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Songliao, Jianghan, Tuha, Tarim and Junggar basin in China [1]. Nevertheless, mineral composition, organic content, microstructure of rock, reservoir thickness and burial depth of shale formation in these basins are different from which in North America. Especially, deeper burial depth of shale gas reservoirs in China make operations such as drilling, completion, fracturing very difficult, leading that many key technology problems should be solved before shale gas could be produced commercially in large scale [2]. Shale gas reservoirs explored and had been put into commercial exploitation were only found in South China especially in Sichuan basin up to now. Logging data analysis indicated that there were three sets of grey brown oil shale formation (thickness is 92m, 233m, 37m separately, $\Sigma(C_1\text{-}C_4)$ from tank top gas logging analysis results of many cuttings was up to 25587.277 μL/L) developed in Shahejie Group of Paleogene System in Jiyang depression of Bohai Gulf [3]. Because of the characteristics of low porosity and low permeability of shale, it is difficult to detect shale physical properties and influencing factors, which restricts the development of shale property evaluation [4]. Logging and laboratory experiments were the main methods to analyze the physical properties of shale gas reservoirs. Physical property evaluation of shale gas reservoir mainly includes porosity, permeability and saturation of reservoir [5]. Therefore, the purpose of this paper is to investigate the physical and chemical properties of shale from Shahejie group of Jiyang depression for making sure that whether this shale gas reservoir is suitable for producing commercially and give the guides for drilling and exploitation.

2. EXPERIMENTAL

2. 1. Materials Shale cores and fragments were collected from Shahejie group of Jiyang depression located in Bohai Gulf. There were several sets of gas source rocks including Stone carbon-dyas paralic hydrocarbon source rocks, Mesozoic erathem limnetic facies source rocks and Paleogene System lacustrine facies bearing rocks. Other additives and chemicals were all analytical grade and purchased from Sinopharm Chemical Reagent Co., Ltd (SCRC), Peking, China.

2. 2. Analysis of Compositions and Microstructure Some of shale fragments were first ground into powder: a part of them less than 150 μm; others no bigger than 58μm. About 30 grams shale powder smaller than 58μm were used in mineral composition analysis through X-ray diffraction (XRD) using Rigaku D/max-IIIA to test whole rock mineral and relative contents of clay minerals. About two grams of shale powder smaller than 150μm were used in total organic carbon (TOC) analyzing by CS230 carbon-sulfur analyzer purchased from LECO Company of United States [6]. Several shivers of shale rock were shattered with fresh section for observing microstructure through S-4800 scanning electron microscope (SEM).

2. 3. Measurements of Porosity, Pore Diameter, Specific Area and Permeability True density, porosity, pore diameter and Langmuir specific area were all measured through nitrogen adsorption (NA) in low temperature using shale cores [7]. True density and porosity were tested by 3H-2000TD2 full automatic true density and porosity measuring instrument, pore diameter and Langmuir specific area were determined by 3H-2000PS1 full nitrogen adsorption surface area and pore size analyzer after shale cores dried and outgassed at 423 K for 5 hours, ensuring the removal of bound water adsorbed in the clays. For comparison, pore diameters were also tested by high pressure mercury intrusion (HPMI) through AutoPore 9505 equipment (SY/T 5346-2005) using core samples [8], specific area was measured by methylene blue trihydrate method (MBT) using shale powder less than 150 μm. The permeability of shale cores was tested by the pressure pulse decay method on TEMCO PDP-200 with high purity methane as medium according to American Petroleum Institute Standard (API RP-40).

2. 4. Tests of Adsorption Isotherm Adsorption of methane on shale surface adhere to Langmuir adsorption isotherm relationship, volume of methane in free state can be figured out by gas equation of real state after adsorption equilibrium achieved. The analytical results include Langmuir volume and Langmuir pressure. Shale powder samples whose diameter between 178 μm and 250 μm were sieved and dried for 24 hours at 105℃ before the methane adsorption experiments. All methane adsorption was measured at temperatures of 25℃, 50℃, 75℃ and under pressures up to a consistent pressure of 6 MPa.

2. 5. Analysis of other Physicochemical Properties The cation exchange capacities (CEC) of shale from Shahejie group of Jiyang depression were determined by methylene blue trihydrate method after ground less than 150 μm [9]. The hydration properties were tested through shale dispersion experiment for dispersion properties using fragment with size between 2mm and 5mm, shale expansion experiment for swelling properties using shale powder smaller than 150 μm according to API standard. The shale stability indexes (SSI) were measured by needle penetration method using small shale particles between 250 μm and 180 μm. The SSI can be calculated through the following Equation (1).

$$\text{SSI}=102-2(H_f-H_i)-4\Delta H \quad (1)$$

where, H_f is the needle penetration of shale after water sucking, mm; H_i is the needle penetration of shale before water sucking, mm; ΔH is swelling capacity of shale, mm.

Moreover, the specific water wettability (SWW) defined as water absorbing capacity on unit area of shale was figured out using total suction divided by specific surface area:

$$S_w = \frac{w_2 - w_1}{10000 * S_s (w_1 - w_0)} \quad (2)$$

where S_w is the specific water wettability of shale, 10^{-7} g/m^2; W_2 is the weight of shale power after water sucking, g; W_1 is the weight of shale power oven dried 5 hours under 105℃ before water sucking, g; W_0 is the weight of container, g; S_s is the specific surface area of shale powder, m^2/g. The total water suction was determined by water vapour adsorption, the specific surface area through methylene blue trihydrate method [10].

3. RESULTS AND DISCUSSION

3. 1. Inorganic Mineral and TOC It can be seen from XRD analysis results listed in Table 1 that main inorganic mineral compositions of shale from Shahejie group of Jiyang depression are quartz, calcite and clay. The specific content of them is shown in Table 1. The brittleness indexes, which means the percentage of brittle mineral (quart, calcite, feldspar, dolomite) in total inorganic mineral (quart, calcite, feldspar, dolomite, clay and so on), ranged from 62 to 79% and averaged 69.9%. High brittleness index leads to the formation of fractures, which are the main seepage channels of shale gas. So shale in Jiyang depression is excellent fracturing formation. The clay mineral and their relative amount are presented in Table 2. Main components of clay mineral in shale are illite, mixed-layer of illite and smectite (I/S), whose average relative content are 69.29 and 27.38%, respectively. Illite has the characteristics of weak expansion and breakable, and high content of illite is favorable for fracturing. In shale samples, the TOC content is 2.86% on average, and ranges from 1.84% to 4.92%, with small diversity and wirkungsgehalt forming shale gas reservoirs (Table 1).The sulphur content ranges from 2.45 to 7.93%, with an average of 4.90% (Table 1), which may have a high concentration of sulphur-bearing shale gas.

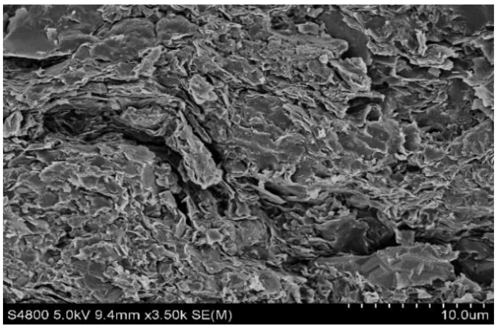
TABLE 1. Results of mineral composition analysis by X-ray diffraction

Sample	Quartz (%)	Potash Feldspar (%)	Anorthose (%)	Calcite (%)	Ankerite (%)	Siderite (%)	Iron pyrite (%)	Clay (%)	TOC (%)	Sulfur content (%)	Brittleness Index (%)
D1	25	6	15	22	3	1	4	24	2.61	7.21	71
D2	28	7	15	11	3	1	4	31	4.92	6.50	64
D3	29	0	7	32	0	4	3	25	2.63	4.87	68
D4	31	5	3	26	3	0	0	32	2.82	6.29	68
D5	26	8	12	33	0	2	1	18	2.96	7.93	79
D6	29	7	14	28	1	1	3	17	2.34	4.67	79
D7	34	4	8	19	3	1	5	26	1.96	3.82	68
D8	32	0	11	26	2	1	4	24	3.27	4.95	71
D9	23	1	12	30	1	0	2	31	2.98	2.88	67
D10	28	3	13	27	3	2	1	23	3.18	6.78	74
D11	31	3	15	24	0	2	4	21	3.06	5.04	73
D12	27	7	6	31	1	3	3	22	2.88	6.31	72
D13	31	5	5	22	4	2	2	29	2.47	4.84	67
D14	30	8	8	27	5	1	0	21	2.52	5.45	78
D15	27	6	3	30	0	4	0	30	1.84	3.77	66
D16	29	5	0	28	1	3	2	32	2.28	4.19	63
D17	35	0	4	27	0	1	0	33	2.66	3.36	66
D18	29	6	7	31	2	1	3	21	3.69	2.82	75
D19	28	4	6	32	1	0	4	25	2.84	5.93	71
D20	25	3	9	25	0	2	3	33	2.72	2.45	62
D21	27	6	11	21	1	1	2	31	3.41	4.50	66

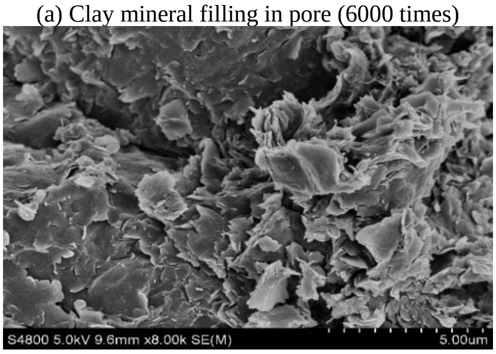
TABLE 2. Results of the relative content analysis of clay minerals

Sample	Kaolinite (%)	Chlorite (%)	Illite (%)	I/S (%)	Interlaying Ratio of I/S (%)
D1	2	2	67	29	20
D2	2	2	69	27	20
D3	2	1	69	28	20
D4	2	2	67	29	20
D5	2	2	69	27	20
D6	2	1	69	28	20
D7	1	1	71	27	20
D8	2	1	74	23	20
D9	1	1	74	24	20
D10	1	1	72	26	20
D11	3	1	68	28	20
D12	1	2	64	33	20
D13	1	1	67	31	20
D14	2	2	65	31	20
D15	2	2	72	24	20
D16	1	3	70	26	20
D17	1	2	68	29	20
D18	3	1	69	27	20
D19	2	1	65	32	20
D20	3	1	73	23	20
D21	2	2	71	25	20

3. 2. Microstructure SEM images of shale sample D1 and D21 are shown in Figures 1 and 2, respectively. The microfracture and micropore were developed. The parallel lamellation were found in the images. The microfracture is important drainage channel for shale gas. But filtration and slurry of drilling fluid can invade into formation through these channels. So these microfractures must be plugged during drilling. The lamellation is helpful to form horizontal fracture during fracturing stimulation. The microstructure characteristics of shale from Shahejie group of Jiyang depression indicate that the objective formation possess a certain permeability for shale gas, but also maybe lead loss of drilling fluid, instability of well bore, velocity sensitivity damage.

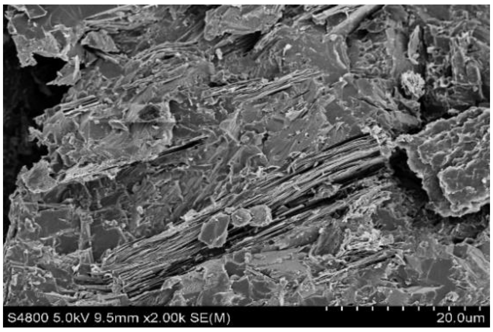


(a) Clay mineral filling in pore (6000 times)

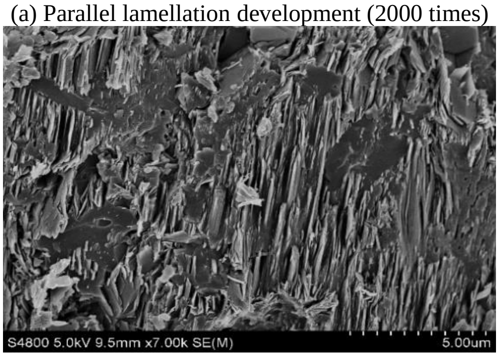


(b) Clay mineral (8000times)

Figure 1. SEM images of shale sample D1



(a) Parallel lamellation development (2000 times)



(b) Detrital particle corroded (7000 times)

Figure 2. SEM images of shale sample D21

3. 3. Porosity, Pore Diameter, Specific Area and Permeability The average porosity of shale samples is 3.77%, and the average methane permeability is 0.011×10-3 cm^2, which is larger than the permeability of shale in Sichuan Basin [10]. The average true density is 2.69 g/cm^3, which is basically consistent with the average true density of natural shale. Pore diameters tested by nitrogen adsorption (test curve of sample D21 shown in Figure 3) ranged from 3.92 to 11.24 nm, with an average of 7.64 nm. While pore diameters measured by high pressure mercury intrusion ranged from 4.38 to 14.78 nm, with an average of 10.46 nm (test curve of sample D21 shown in Figure 4), which is larger than NA ones. The reason is that the high capillary force must be overcome to drive mercury enter pindling pore. Even the test pressure in experiment was up to 227.545 MPa. There are still many pores that have not been filled with mercury. (Figures 4 and 5). Test results of NA pore diameter could be affected by adsorption state of nitrogen on internal wall of shale pores, for example whether this adsorption follows Langmuir rules or not. There was a well positive correlation between results measured by two different methods (r=0.79, Figure 6). The nitrogen adsorption method was better for characterizing shale samples with smaller pores. Internal surface area of shale cores measured by nitrogen adsorption (Langmuir surface area) averaged 0.91 m^2/g and ranged from 0.4 to 1.34 m^2/g, while surface area of shale powder tested through methylene blue trihydrate (MBT) method ranged from 45 to 68.6 m^2/g with a larger average of 57.56 m^2/g, which has positive correlation with Langmuir surface area (Figure 7). Langmuir surface area could reflect shale's adsorption features, and MBT surface area has better guidance for hydration characteristic of shale, which were used in calculating specific water wettability.

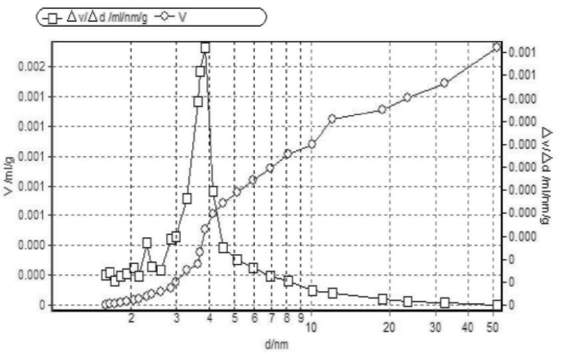


Figure 3. BJH differential, integration hole volume and pore diameter curve of sample D21

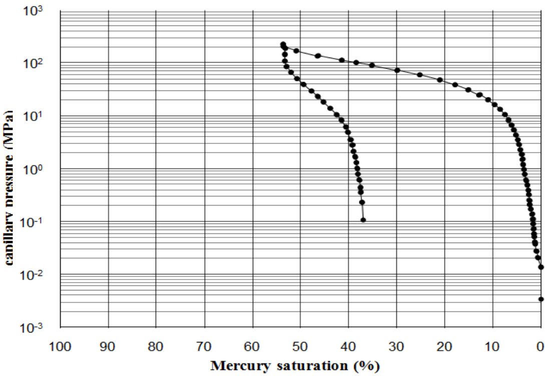


Figure 4. Capillary pressure curve of sample D21

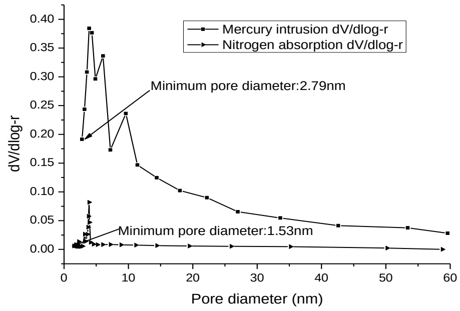


Figure 5. Differential volume and pore diameter curve of sample D21 by N_2 adsorption and mercury intrusion

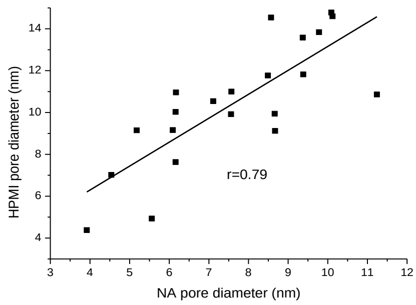


Figure 6. Relation between NA pore diameters and HPMI pore diameters

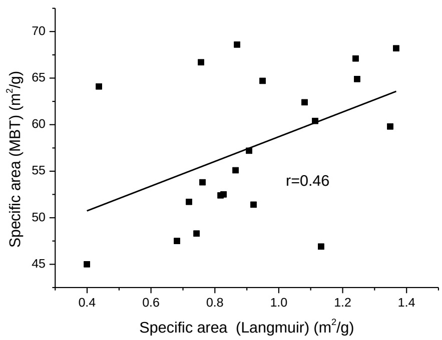


Figure 7. Relation between NA specific areas and MBT specific areas

3. 4. Adsorption Characteristic for Methane and its Relativity with other Parameters

3. 4. 1. Effect of Temperature and Pressure

Langmuir volumes of methane adsorbed on shale samples averaged 5.82 cm^3/g (between 3.48 cm^3/g and 7.69 cm^3/g) at 25 ℃, 4.83 cm^3/g (from 2.94 cm^3/g to 6.38 cm^3/g) at 50 ℃ and 4.01 cm^3/g (between 2.62 cm^3/g and 5.38 cm^3/g) at 75℃. As temperature increased, the Langmuir volume droped, while the Langmuir pressure enlarged. Adsorptive capacity of methane adsorbed on shale samples grew with pressure increasing and reduced at elevated temperature (Figure 8). The reason is that molecular kinetic of methane gas intensify with temperature rising, and the differential pressure of methane in adsorption tank enlarges with pressure increasing. This phenomenon indicates that shale gas is easier to desorb from internal surface of shale pores by lower pressure and keep the formation temperature.

3. 4. 2. Relation between Langmuir Volumes and other Parameters In statistics, Karl Pearson correlation theory is the most simple, intuitionistic and conventional method used in investigating the correlation between two variables. The Pearson product-moment correlation coefficient (r) reflects the degree of linear relationship between two variables. It can be computed through Equation (3) [11]:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (3)$$

where, x and y are two variables; (x_i, y_i) (i=1,2,3,…n) are n pairs of variables; $\bar{x}$ and $\bar{y}$ are averages of variables. The “r” ranges from +1 to -1. A correlation of +1 means that there is a perfect positive linear relationship between variables. -1 means that there is a perfect negative linear relationship between variables. 0 means there is no linear relationship between the two variables. The linear relationship between variables can be classified into four grades according to the value of $|r|$: weak correlation ($|r|$ =0~0.3), low correlation ($|r|$ =0.3~0.5), moderate correlation ($|r|$ =0.5~0.8), high correlation ($|r|$ =0.8~1). The relationship between Langmuir volumes and other parameters was studied in detail by Karl Pearson correlation theory. Pearson product-moment correlation coefficient and linear fitting between Langmuir volumes and other parameters were listed in Table 3. It can be seen from Table 3 that Langmuir volumes of shale samples were positively correlated with TOC, content of clay mineral, Langmuir specific area and pore diameter under 25 ℃, 50 ℃ and 75 ℃. As literature had shown that methane adsorption capacity of shales is dependent on geological control factors including TOC content, kerogen types, mineralogy, pore structure. TOC was thought as a critical control on methane adsorption and storage for shale because CH_4 bituminite. There was a low positive relationship between TOC and Langmuir volume of shale in Jiyang depression evidenced by smaller Pearson coefficient (Figure 9) attributed to it lower content and the effect of clay mineral (Figure 10). Clay minerals can adsorb methane and the adsorption capacity depends on the development of nano-scale micropore and the specific surface area size specific area [12]. Role of clay mineral in methane adsorption and storage would be enhanced when the content of organic matter in shale was lower. There is a moderate positive relationship between Langmuir volume and Langmuir specific area of shale in Jiyang depression with big Pearson coefficient (Figure 11). This indicates that Langmuir specific area is a key of methane adsorption and storage of shale from Shahejie group in Jiyang depression. The relation line does not go through the origin of the Langmuir specific area - Langmuir volume plot, which may be related to dissolution of methane gas in matrix bituminite. Micropore and microfracture mainly serve as shale gas transport channel,s so pore diameter size have a weak positive correlation with Langmuir volumes of shale samples with smallest r shown in Figure 12. Pore structure affects the permeability, porosity and internal surface area of shale and plays an important role in the storage and exploitation.

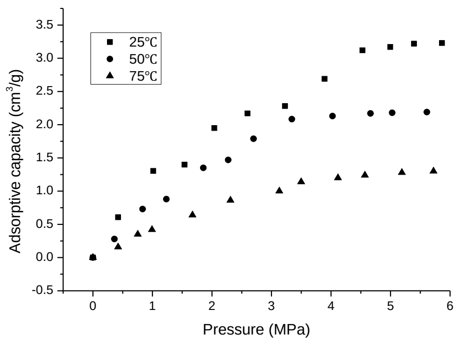


Figure 8. Adsorptive capacity of methane adsorbed on shale sample D1 under different temperature

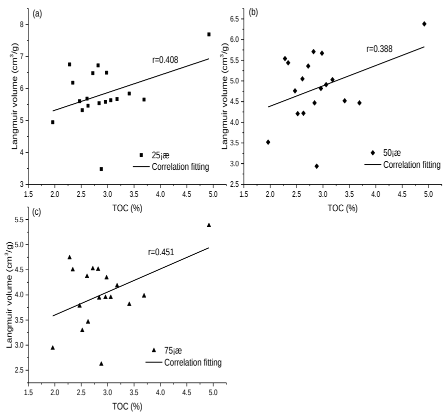


Figure 9. Relation between Langmuir volumes and TOC under different temperature

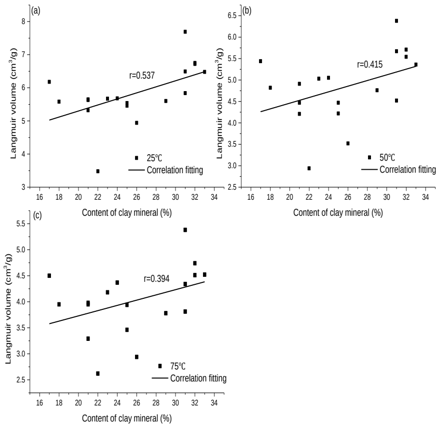


Figure 10. Relation between Langmuir volumes and content of clay mineral under different temperature

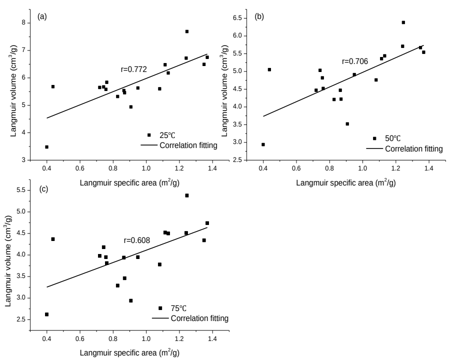


Figure 11. Relation between Langmuir volumes and Langmuir specific area under different temperature

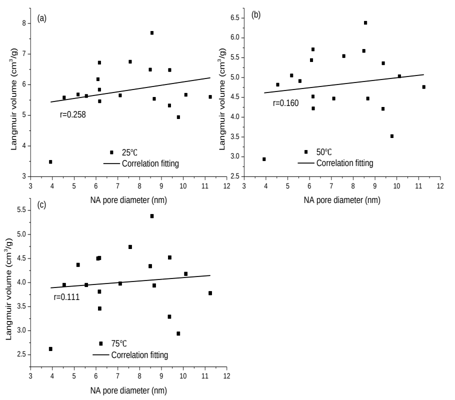


Figure 12. Relation between Langmuir volumes and NA pore diameter under different temperature

3. 5. CEC, Hydration Capacity, Specific Water Wettability and SSI

Other physicochemical properties of shale samples from Shahejie group in Jiyang depression were tested. CEC of samples ranged from 21.84 mmol/kg to 30.82 mmol/kg with a smaller an average of 92.57%, showing that the analysed shale has weak hydration dispersing capacity. Linear swelling rates were between 6.04 and 9.49% with an average of 7.43%, indicating that the shale samples has lower hydrating and swelling performance. But swelling rates were very high at the initial stage, and it increased slowly after half an hour and run up to maximum within 8 hours (Figure 13). Specific water wettability was considered to be a more effective index in reflection of hydration repulsion of mud rock and shale because its physical significance is the thickness of hydration shell. The bigger SWW is, the higher hydration swelling pressure will be and the easier well bore collapse. The average of SWW is 4.36×10^{-7} g/m^2, illustrating that hydration repulsion of shale samples were huge and would cause the borehole collapse. The shale stability index is a comprehensive indicator used to denote the stability of mud rock and shale formation, which can reflect the hydration dispersion, swelling and strength after sample contact with tested fluid (water or drilling fluid) synthetically. The stability of formation can be divided into four ranks according to the value of SSI: high stability (SSI>90 mm), moderate stability (SSI=60~90 mm), low stability (SSI=30~60 mm), weak stability (SSI <30 mm). SSI of shale samples, with an average of 19.99 mm (<30mm), showed shale formation of Shahejie group in Jiyang depression has poor stability [13].

3. 6. Geological and Engineering Significance

Statistical test results of shale samples listed in Table 4 indicated that shale reservoir in Jiyang depression has fairly good physical and chemical characteristics: suitable TOC (2.86%) for hydrocarbon generation; enough brittle mineral (69.9%), less clay mineral

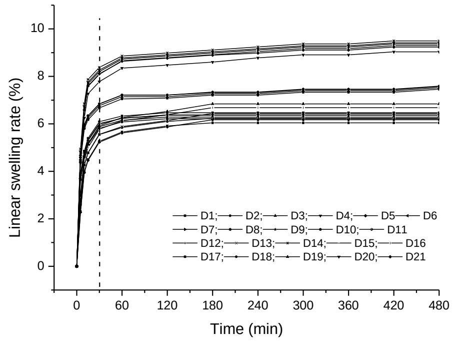


Figure 13. Linear swelling rate changes of shales from Shahejie group in Jiyang depression with time

TABLE 3. Linear fitting between Langmuir volumes and other parameters

Variable 1(X)	Variable 2(Y)		Fitting equation	Pearson coefficient	Relationship
TOC	Langmuir volume	25 °C	Y=4.216+0.551X	0.408	Low
		50 °C	Y=3.407+0.492X	0.388	Low
		75 °C	Y=2.682+0.459X	0.451	Low
Content of clay mineral	Langmuir volume	25 °C	Y=3.473+0.091X	0.537	Moderate
		50 °C	Y=3.136+0.067X	0.415	Low
		75 °C	Y=2.722+0.050X	0.394	Low
Langmuir specific area	Langmuir volume	25 °C	Y=3.569+2.412X	0.772	Moderate
		50 °C	Y=2.907+2.689X	0.706	Moderate
		75 °C	Y=2.683+1.429X	0.608	Moderate
Pore diameter	Langmuir volume	25 °C	Y=5.013+0.108X	0.258	Weak
		50 °C	Y=4.366+0.062X	0.160	Weak
		75 °C	Y=3.753+0.034X	0.111	Weak

(26.14%) for fracturing; higher permeability (0.011V) for methane supplying better flow channel; appropriate porosity (3.77%) and Langmuir specific area (0.91 m^2/g) for storage of shale gas in free and adsorbed states; effective thickness of 130.66m for recovery.

Meanwhile, there were several problems related to reservoir damage, instability of borehole and loss circulation during drilling and exploiting determined from results of physical and chemical properties. High content of illite (69.29%) maybe lead to serious fine migration and velocity sensitivity damage. Also, nanoscale pore and microfracture (7.64 nm) caused high capillary force (up to 227.545MPa) and water lock is easy to cause permeability reduction of formation and check flow back of fracturing liquid.

Down hole problems include borehole instability caused by large SWW ($4.3610^{-7} g/m^2$) and small SSI (19.99mm) of shale formation in Shahejie group of Jiyang depression, filtration, invasion and loss of drilling fluid due to microfracture and lamellation.

So some countermeasures must be adopted during drilling and fracturing. Oil based drilling fluid; water based working fluid with micro and nano materials, asphalt, membrane-forming agent are wellbehaved working fluid, which can reduce filtration, improve salinity and enhance plugging capacity.

TABLE 4. Physical and chemical characteristics of shale samples from Jiyang depression and their significance in drilling and exploitation

Items	Parameters	Range of results	Averages	Geological significance	Engineering values	
					Drilling	Exploitation
Organic matter	TOC (%)	1.84-4.92	2.86	Meet reservoir forming condition	---	---
Inorganic mineral	Brittle mineral content (%)	62-79	69.9	Meet reservoir forming condition	Be fit for Improving speed	Be fit for fracturing
	Clay mineral Content (%)	17-33	26.14	Meet reservoir forming condition	Lead to side wall unstable	Be fit for fracturing
	Content of expansive clay minerals (%)	20	20	Meet reservoir forming condition	Lead to side wall unstable	Be fit for fracturing
Properties of reservoir	Porosity by NA (%)	0.92-8.18	3.77	Meet reservoir forming condition	---	Adaptive for recovery
	Permeability ($10^{-3}\mu m^2$)	0.0037-0.0204	0.011	Better physical properties	---	Need be fractured
	Pore diameter by NA (nm)	3.92-11.24	7.64	Better physical properties	---	Adaptive for recovery

	Pore diameter by HPMI (nm)	4.38-14.78	10.46	Better physical properties	---	Adaptive for recovery
	Specific area by NA (m^2/g)	0.4-1.37	0.91	Better physical properties	---	---
	Specific area by MBT (m^2/g)	45-68.6	57.56	---	Calculating SWW	---
Adsorption	V_L(25℃) (cm^3/g)	3.48-7.96	5.82	Better physical properties	---	Adaptive for recovery
	CEC (mmol/kg)	21.84-30.82	26.32	---	Lead to side wall unstable	---
Hydration properties and stability of borehole	Swelling rate (%)	6.04-9.49	7.43	---	Lead to side wall unstable	---
	Recovery (%)	88.74-96.97	92.57	---	Lead to side wall unstable	---
	SWW ($10^{-7}g/m^2$)	2.75-5.77	4.36	---	Lead to side wall unstable	---
	SSI (mm)	7.34-32.48	19.99	---	Lead to side wall unstable	---
Thickness of shale		67-233	130.6	Meet reservoir forming condition	Difficult to drill through	Adaptive for recovery

4. CONCLUSIONS

The following conclusions have been reached based on the measurement of physical and chemical characteristics of shale samples, the detail discussion of their correlation, the geological and engineering significances. Pore diameters of samples tested by high pressure mercury intrusion were larger than that by nitrogen adsorption. Nitrogen adsorption method is suitable for characterizing smaller pores of shale. There was a well positive correlation between results tested by two different methods. Internal surface area of shale cores measured by nitrogen adsorption (Langmuir surface area) has a positive correlation with surface area of shale powder tested through methylene blue trihydrate. Langmuir surface area could reflect shale's adsorption features very well, MBT surface area had better guidance for hydration characteristic of shale and was used in calculating specific water wettability. Langmuir volumes of shale samples were positively correlated with TOC, clay mineral content, Langmuir specific area, pore diameter under 25 ℃, 50 ℃, 75 ℃ and affected by several geological factors at the same time evidenced by the lower Pearson coefficient between Langmuir volume and each factor. There were several problems related to reservoir damage, instability of borehole and loss circulation during drilling and exploiting determined from results of physical and chemical properties.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Tonglou, G., "Key geological issues and main controls on accumulation and enrichment of chinese shale gas", ***Petroleum Exploration and Development***, Vol. 43, No. 3, (2016), 349-359. http://doi.org/10.1016/j.energy.2011.09.001
2. Chen, S., Zhu, Y., Wang, H., Liu, H., Wei, W. and Fang, J., "Shale gas reservoir characterisation: A typical case in the southern sichuan basin of china", ***Energy***, Vol. 36, No. 11, (2011), 6609-6616. http://doi.org/10.1016/s1876-3804(16)30042-8
3. Nie, H., Zhang, J. and Li, Y., "Accumulation conditions of the lower cambrian shale gas in the sichuan basin and its periphery", ***Acta Petrolei Sinica***, Vol. 32, No. 6, (2011), 959-967.
4. Romero-Sarmiento, M.-F., Ducros, M., Carpentier, B., Lorant, F., Cacas, M.-C., Pegaz-Fiornet, S., Wolf, S., Rohais, S. and Moretti, I., "Quantitative evaluation of toc, organic porosity and gas retention distribution in a gas shale play using petroleum system modeling: Application to the mississippian barnett shale", ***Marine and Petroleum Geology***, Vol. 45, No., (2013), 315-330. http://doi.org/10.1016/j.marpetgeo.2013.04.003
5. GUO, X., HU, D., LI, Y., LIU, R. and WANG, Q., "Geological features and reservoiring mode of shale gas reservoirs in longmaxi formation of the jiaoshiba area", ***Acta Geologica Sinica-English Edition***, Vol. 88, No. 6, (2014), 1811-1821. http://doi.org/10.1111/1755-6724.12347
6. Akhtarmanesh, S., Shahrabi, M.A. and Atashnezhad, A., "Improvement of wellbore stability in shale using nanoparticles", ***Journal of Petroleum Science and Engineering***, Vol. 112, No., (2013), 290-295. http://doi.org/10.1016/j.coal.2012.06.012
7. Klaver, J., Desbois, G., Urai, J.L. and Littke, R., "Bib-sem study of the pore space morphology in early mature posidonia shale

from the hils area, germany", ***International Journal of Coal Geology***, Vol. 103, No., (2012), 12-25. http://doi.org/10.1016/j.petrol.2013.11.022

8. Labani, M.M., Rezaee, R., Saeedi, A. and Al Hinai, A., "Evaluation of pore size spectrum of gas shale reservoirs using low pressure nitrogen adsorption, gas expansion and mercury porosimetry: A case study from the perth and canning basins, western australia", ***Journal of Petroleum Science and Engineering***, Vol. 112, No., (2013), 7-16.
9. Shaobo, T.H.Z.S.L. and ZHANG, H., "Determination of organic-rich shale pore features by mercury injection and gas adsorption methods [j]", ***Acta Petrolei Sinica***, Vol. 3, No., (2012). http://doi.org/10.1180/claymin.2009.4.421
10. Środoń, J., "Quantification of illite and smectite and their layer charges in sandstones and shales from shallow burial depth", ***Clay Minerals***, Vol. 44, No. 4, (2009), 421-434. http://doi.org/10.1016/j.petrol.2013.11.017
11. Yang, F., Ning, Z. and Liu, H., "Fractal characteristics of shales from a shale gas reservoir in the sichuan basin, china", ***Fuel***, Vol. 115, No., (2014), 378-384. http://doi.org/10.1016/j.fuel.2013.07.040
12. Ji, L., Qiu, J., Xia, Y. and Zhang, T., "Micro-pore characteristics and methane adsorption properties of common clay minerals by electron microscope scanning", ***Acta Petrolei Sinica***, Vol. 33, No. 2, (2012), 249-256.
13. Xu, Y.-M., He, D.-M., Guan, J. and Zhang, Q.-M., "Preparation of alumina from retorting residue of oil shale", ***Oil Shale***, Vol. 29, No. 1, (2012). http://doi.org/10.3176/oil.2012.1.04

Persian Abstract

چکیده

خصوصیات فیزیکی و ژئوشیمیایی شیل نقش موثری در تأیید اقدامات عملیاتی حین حفاری و تحریک دارد. خواص نمونه های شیل از پراکنش جیانگ از طریق پراش اشعه ایکس ، میکروسکوپ الکترونی روبشی ، ایزوترمال جذب ، نفوذ جیوه با فشار بالا ، تری هیدرات متیلن آبی ، پوسیدگی فشار پالس ، تست مقاومت به خاصیت خیس شدن آب و شاخص پایداری شیل بررسی گردید. همبستگی ، اهمیت زمین شناسی و مهندسی آنها مورد بحث قرار گرفت. نتایج نشان می دهد که مخزن شیل در پراکنش جیانگ دارای ارزش بهره برداری با پارامترهای مشخصه خوب تأیید شده است: ٪۲/۸۶ TOC، ٪۶۹.۹ مواد معدنی شکننده ، معدنی خاک رس ٪۲۶.۱٤ ، نفوذپذیری بالا از μm^2 ×۱۰^-۳^ 0.011، حجم بزرگ لانگمویر (۵.۸۲ g/cm^3) و منطقه خاص لانگمویر (۰/۹۱ مترمربع در گرم) ، تخلخل مؤثر (٪۳/۷۷) و ضخامت (۱۳۰/٦ متر). منطقه خاص لانگمیر کنترل اصلی در جذب و ذخیره متان است که با توجه به نسبت نسبی مثبت آن با حجم لانگمویر به جای TOC تأیید شده است. محتوای بالای Illite (69.29 ٪) (ممکن است به بی ثباتی آسیب چاه و حساسیت به سرعت منجر شود. ریزساختارها کانالهایی را برای تصفیه ، تهاجم و از بین رفتن مایع حفاری فراهم می کنند. خاصیت خیس شدن خاص آب (۱۰^-۷^ ×٤/۳٦گرم بر مترمربع) و شاخص پایداری شیل کوچکتر (۱۹/۱۹ میلی متر) باعث شده است که تشکیل شیل یک بار در تماس با آب شیرین ناپایدار باشند. اقدامات متقابل باید در حین حفاری و شکستگی اتخاذ شود تا آسیب مخزن و شرایط پیچیده فروپاشی کاهش یابد.