STUDY ON THE EFFECT OF SHALE SWELLING AND DISPERSION CHARACTERISTICS ON SHALE GAS FRACTURING

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Abstract: Developing shale gas reservoirs by fracturing treatment often associates with large amount of fluid and high flow rate. Shale reservoir often contains clay minerals of a certain proportion, but fluid and displacement of a large amount may cause swelling of clay minerals and hydration dispersion. Relevant evaluation system has not established on current research work within this area till now. So, with reference to previous research results, combined with capillary suction time(CST)、swelling experiment and x ray diffraction(XRD)analysis of mineral composition, effects of different working fluids medium on shale swelling and dispersion have been revealed, which is significant for well stability in drilling wells and fracturing designs optimization in shale reservoirs.

Key words: Swelling, Dispersion characteristics, Shale gas, Fracturing

1. Background

For shale gas reservoirs with ability of forming and storing hydrocarbon, large scale volume fracturing treatment must be deployed so as to obtain economic benefits. Thus, fracturing fluid over thousands cubic meters must be used, which is one of the peculiar characteristics that fracturing treatment of shale gas reservoirs differs from conventional gas reservoirs. Similar to other shale gas reservoirs in the other countries, shale gas reservoirs in Sichuan Basin usually have clay minerals with high-content. For some particular shale intervals with highest gas content within a well, 34.1% ~45.9% clay minerals might be contained and they may swell and disperse. We used to believe that little foreign fluids could invade into shale formation, because it is extremely tight and with ultra-low permeability. In the meanwhile, and for the same reason, we try to quantify the effects of clay minerals swelling and dispersion on fracturing treatment in Shale Gas Reservoir by permeability variation, but results are not satisfactory. As a result, clay minerals swelling and dispersion effecting on fracturing treatment of shale gas reservoirs would seldom be considered by permeability variation in the process of fracturing design and post-fracturing estimation.

2. Purpose

Study on shale swelling and dispersion should be implemented through various kinds of analysis methods on the basis of laboratory experiments. Analyze possible effects on shale swelling and dispersion characteristics under different working fluid medium, so as to provide technical support for fracturing design optimization, fracturing fluid selection and post-frac evaluation.

3. Methods

Using the following two experimental methods to study on shale swelling and dispersion:

（1） CST experiment

Using CST methods of fine sizes, core, and core’s bedding plane/ artificial fracture to estimate

various kinds of working fluid's effects on hydration dispersion characteristic and suction of foreign fluid in shale formation.
Fine sizes CST experimental method, which is a kind of filtration time that the fluid with fine shale core sizes of 15% volume fraction (over 100 meshes) have been sheared for different time slots, indicates shale dispersion characteristic. Usually, the time required to migrate the fluid 0.5 cm onto filter paper in the CST instrument is named to be fine sizes CST value. Relation curve could be drawn according to the experimental results and shearing time, and shale dispersion characteristics could be expressed by the following equation:

$$Y = mx+b \quad (1)$$

in the equation , Y-CST value,
m— velocity of shale hydration dispersion
x — shearing time
b—the number of instantaneous cracking particles
Core CST experimental method could establish initial water saturation by simulating formation water and capillary suctions, core sample's weight and electric resistance before absorbing water could be recorded in the meanwhile. Place the core into fluid and immerse (for at least 2 hours) until no further change on weight of the core sample. Relation curve of the core's fluid suction quantity and the suction time could be drawn according to the experimental results; self-suction characteristics under different working fluid medium should be compared.
（2） Swelling Experiment
Place the artificial core into the working mandrel and test the core's swelling rate of the axial line, Relation curve of the core's swelling rate and time could be drawn according to the experimental results, the core's swelling characteristic with different working fluid medium should be compared.

4. Results

(1) CST test
① CST test results of rock fine sizes
In the CST tests of rock fine sizes, we respectively use distilled water, 2% KCL fluid and slick water system with resistance-reducing agent and anti-swelling agent added to make the relevant experiments for the different shale rock fine sizes. Table 1 lists the main mineral compositions. Core sample of 1# with the clay content of 24%, Core sample of 2# with the clay content of 18%, Core sample of 3# with the clay content of 14%. CST comparison results for the three core samples with different coring depths are shown in table 2. Figure 1 shows the CST fitting straight line of the core sample 1# with the equation (1) for three liquids, and the variation rules of CST fitting straight lines for the core sample 2# and 3# for three liquids are almost the same trend as those of the sample 1#.
From the table 1, we get the following results:
test results of the core sample 1# shows among the three fluids, added the 2% KCL fluid, the hydrated and dispersed rate of shale reaches the minimum value, and the number of instantaneous cracking particles also reaches the minimum value. Whereas, with the slick water A#, these above two parameters are the maximum values.
test results for the core sample 2# & 3# are concordant with the core sample 1#.

Test results show that for the rock fine sizes, 2% KCL fluid gives the best inhibition performance for the hydrated and dispersed characteristics of shale, whereas, the slick water A# gives the worst. Additionally, with the mineral composition test results, we analyze the relationship between the CST results of fine sizes and clay mineral content. Figure 2 shows the relationship between the hydrated and dispersed rate of shale and clay mineral content. With the high clay mineral content, 2% KCL fluid and distilled water have good inhibition effects, whereas with the low clay mineral content, the inhibition effects become unapparent. Compared with the other two fluids, the slick water has worse inhibition effects, and its inhibition performance is related to clay content. Figure 3 shows the relationship between the number of instantaneous cracking particles and clay mineral content. Test results shows that with the high clay mineral content, these three fluid systems have the good inhibition performance.

② CST tests results for core samples

Use core samples from two different formation intervals to make CST tests, the main mineral compositions of the two cores are shown in table 3. Figure 4 & 5 show the CST test results of different shale formation intervals.

Form the figure 4 & 5, we can get the following results:

a. Little liquid is suctioned. Both of the figures show that liquid-suction number reaches the maximum value in the early stage. In the first 3 minutes, the liquid-suction rate is large, and then the suction characteristics curve becomes flat, finally liquid-suction rate tends to be 0.
b. For shale formation of 5#，3% KCL fluid gets the maximum suction quantity, whereas 7% KCL and the distilled water(without any additives) get the minimum. For shale formation of 6#, the distilled water fluid system without any additives gets the maximum suction quantity, whereas the 3% KCL and 7% KCL fluid systems get the minimum.
c. Shale with different formation intervals have the great different liquid-suction numbers, which are related to clay mineral content. For core sample 5# with higher clay mineral content and its liquid-suction number is larger than core sample 6#.

③ CST test results for core bedding plane/core samples of artificial fracture

Though suction characteristics of shale matrix are unapparent, for core samples of bedding plane or natural fractures developed, and of artificial fractures, all have the suction characteristics along bedding planes or fractures. Suction rate of artificial fractures is higher than natural fractures due to the much wider artificial cracks. Comparison results of suction rate for artificial fractures and natural fractures are shown in figure 6.

(2) Water suction and swelling test method

Swelling rate of the shale core for two hours approximately equal to the swelling rate of the shale core for sixteen hours, which indicates shale will be swelling when it contacts immigrated fluid, but as time passed, its swelling rate tends to be stabilized. Figure 7 shows the relationship between shale swelling rate vs time for different working fluids. Figure 8 gives the comparatively analyzes for the relationship between shale swelling rate of axial line and clay mineral compositions. Analyzed results indicate that although experiment results of shale swelling are related to clay mineral content, the more the clay mineral contents are, the more closely the relationship between the shale-swelling rate and clay mineral content is.

5. Conclusion

With reference to current experimental research we have performed within this area, characteristics and rules of shale swelling and dispersion could not be revealed thoroughly yet, but some ideas have been gained based on experiments:

(1)In terms of shale reservoirs, because the formation is extremely tight, so it is hard to characterize formation damage caused by foreign fluids according to permeability variation measured by conventional method; however CST experiment and swelling experiment could provide reference to estimate shale gas reservoirs.

(2)Through the shale formation has high-content of clay minerals in the study area, experimental results show that the capacity of total water suction, suction rate and linear swelling rate are very small, but water suction capacity is high in initial period, this could be interpreted as surface wetting phenomenon. Shale swelling and dispersion are obviously distinguishing form conventional mud shale and sandstone with high clay content.

(3)Results of Core CST experiments show that no matter how the clay minerals quantity of the rock contain, though shale rock suction quantity is different, the trends of the suction of the rock is the same: a large amount of sucking and swelling capacity in the previous stage but with a small amount in the later, which is distinguish characteristic differing from the conventional rock such as mud shale or sandstone.

In conclusion，we believe that immigrated liquid will inevitably result in swelling, migration and diffusion of clay minerals in shale formation. However, for the shale reservoirs in Sichuan Basin, based on the study above, we believe that chemical effects are not the main reasons while making the wellbore stability and well fracture designs. With the complicated components and compositions of shale reservoirs, other types of shale reservoirs still needed to be evaluated，but the methods represented in this paper can be expected to provide technology support and guarantee for shale gas development.

Reference literature

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Table 1 main mineral content of different core samples

Core samples No.	Main mineral content %(g)							
	chlorite\ kaolinite	illite\ montmorillonite	quartzite	plagioclase	calcite	ankerite	dolomite	pyrite
1#	4.2	19.7	49.6	4.4	6.8	6.7	1.9	2.1
2#	3.0	14.3	56.3	7.7	4.2	5.7	6.1	2.0
3#	4.7	10.1	24.5	3.8	48.3	1.6	3.8	3.2

Table2 Experimental results of flour CST experiment with different working fluid medium

CST results / Shale Sample No	Distilled Water		2% KCL		Slick Water A#	
	m	b	m	b	m	b
1#	0.062	25.99	0.022	24.65	0.156	41.62
2#	0.076	30.46	0.055	25.19	0.126	70.49
3#	0.069	28.66	0.037	24.89	0.118	50.06

Table 3 main mineral compositions of two cores

Core samples No.	Main mineral content %(g)						
	Total content of clay mineral	gypsum	quartz	plagioclase	calcite	dolomite	ankerite
5#	47.2	0.1	26.7	5.3	10.7	1.2	10.5
6#	26.6	0.7	27.7	27.0	4.7	2.8	

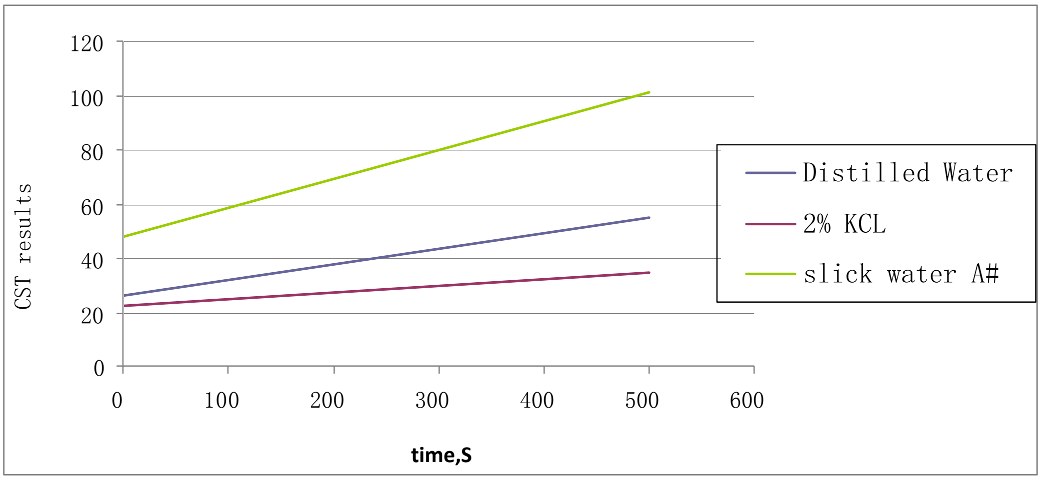

Figure 1 hydration dispersion and swelling characteristic of 1# flour with different working fluid medium

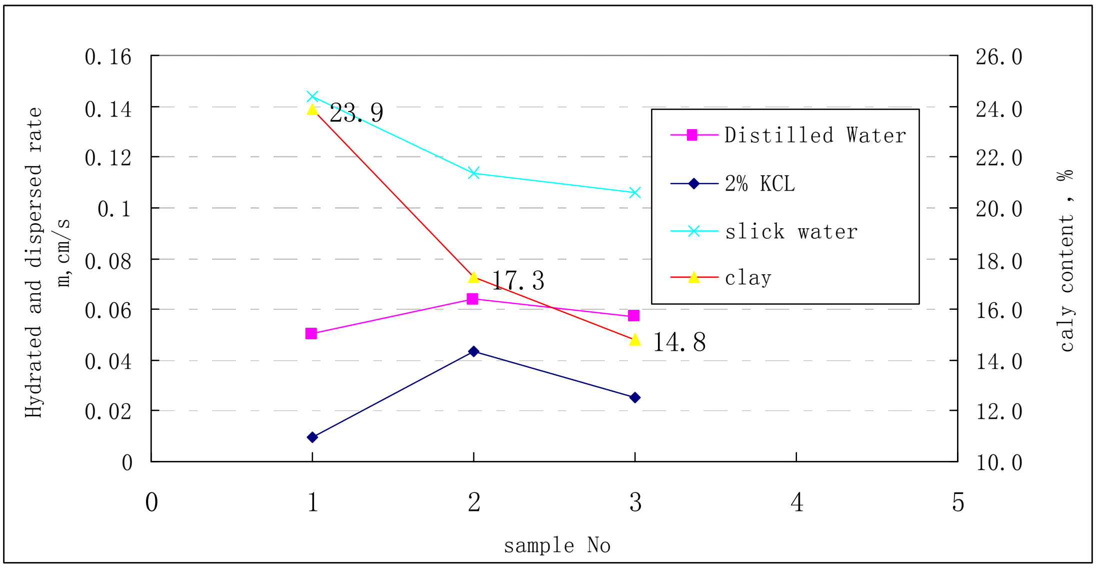

Figure 2 Relation curve of hydration dispersion velocity and clay minerals content of different core samples with 3 different working fluid medium

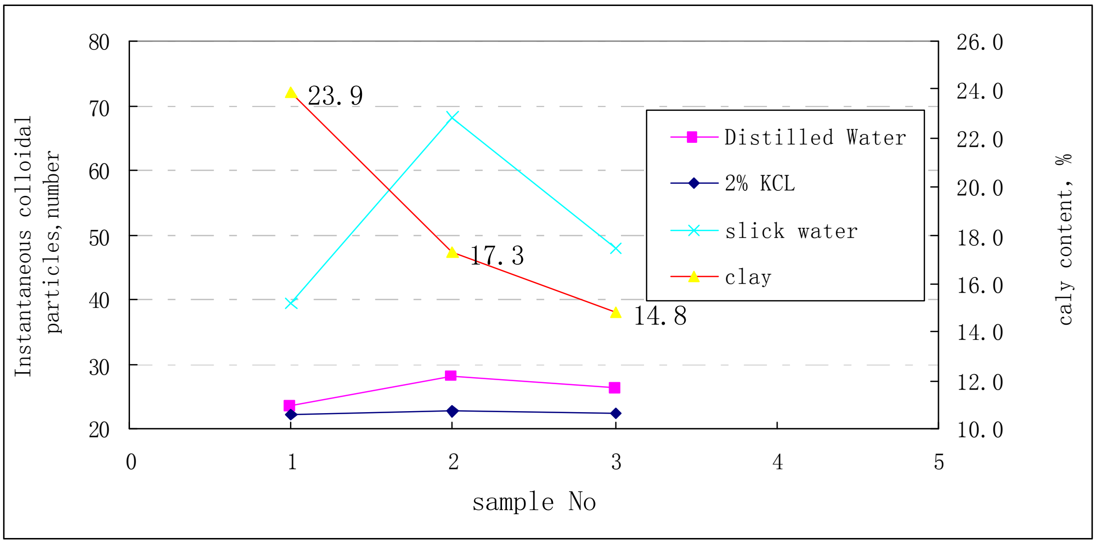

Figure 3 relation curve of instantaneous-breaking gel quantity and clay minerals content of different core samples with 3 different working fluid medium

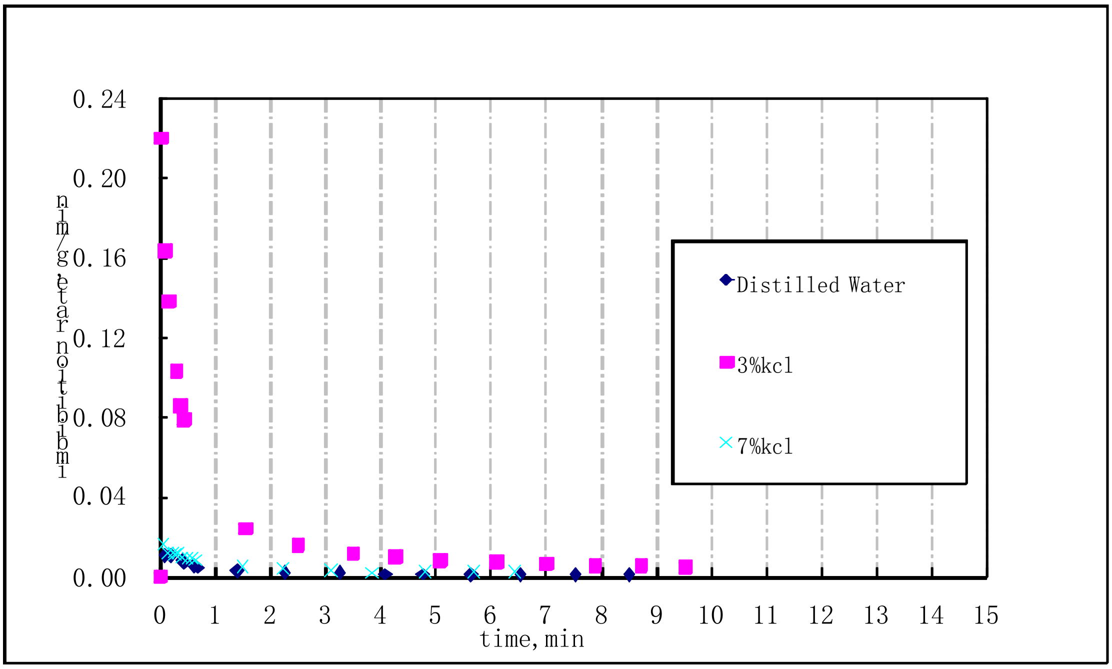

Figure 4 Core CST experiment curve of 5# shale bed in Sichuan Basin

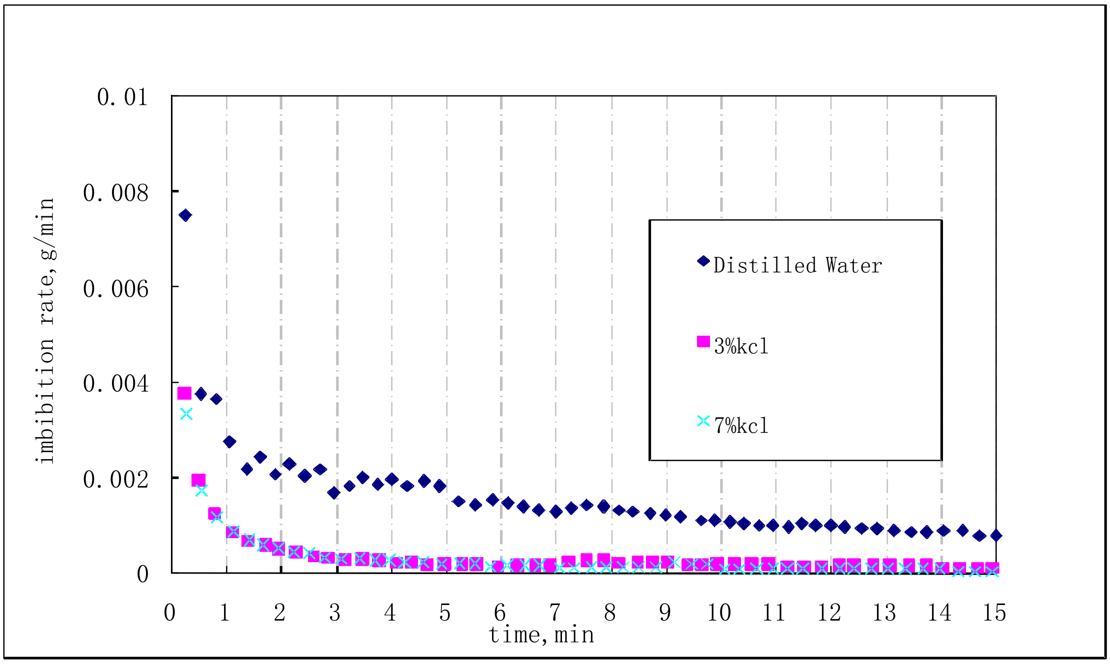

Figure 5 Core CST experiment curve of 6# shale bed in Sichuan Basin

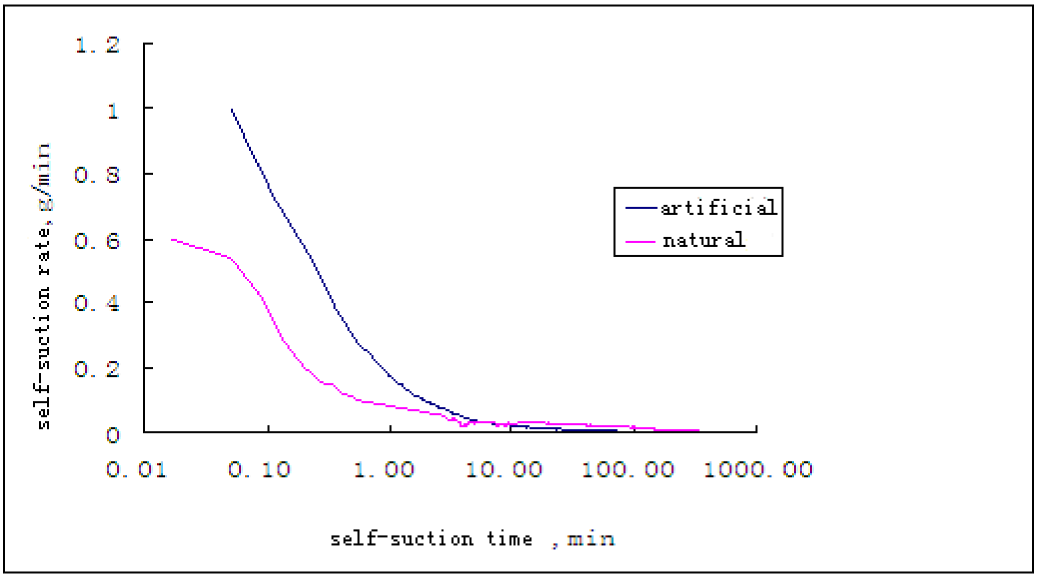

Figure 6 Core CST experiment curve of natural fracture and artificial fracture

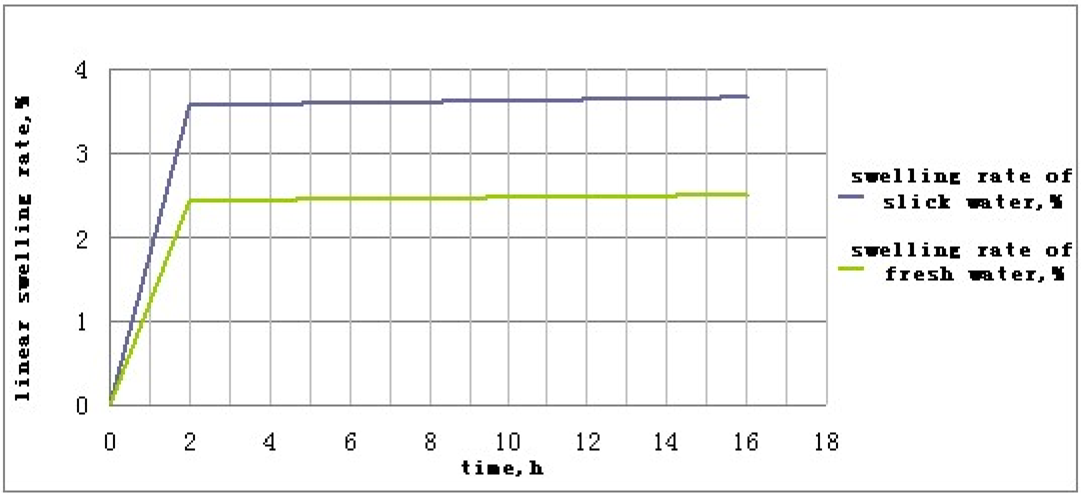

Figure 7　relation curve of shale swelling rate and time with different working fluid medium

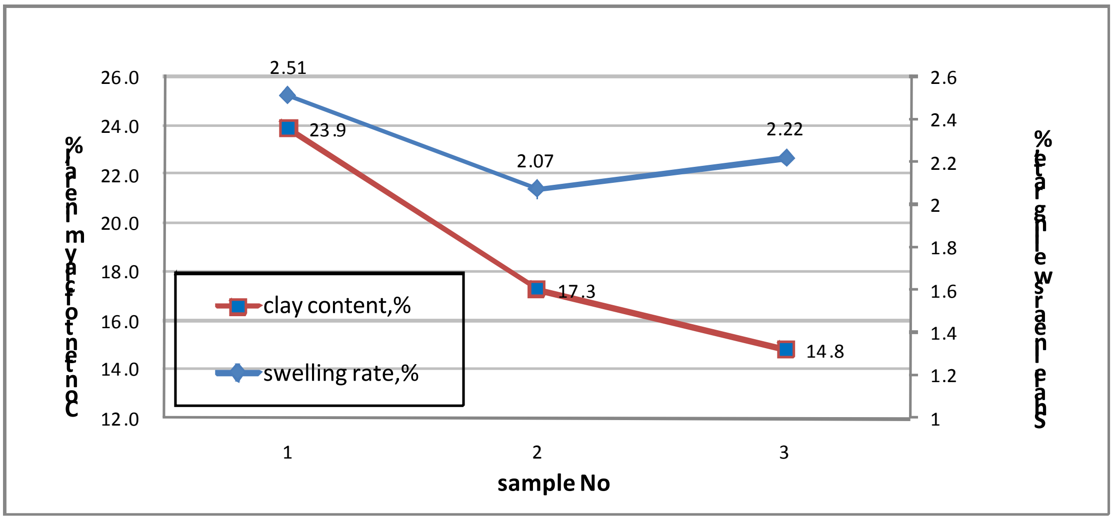

Figure 8 Relation curve of shale swelling rate and clay minerals content of different shale core in slick water