Shale/Mud Inhibition Defined With Rig-Site Methods

M.E. Chenevert, SPE, and **S.O. Osisanya,** SPE, U. of Texas

Summary. The successful drilling of troublesome shale requires evaluation of the shales and muds during the drilling process so that the proper methods and muds can be selected. With rig-site testing in mind, six tests were studied for their usefulness in defining the severity of the shale/mud chemical reaction. All tests showed some value in the analysis of wellbore problems and solutions; however, the swelling, rolling, and cation-exchange-capacity (CEC) tests proved most useful.

The swelling test uses a newly developed device to describe the early-time swelling properties of native or recompacted shale and provides an analytical method for classifying shales according to their reaction rates. In general, soft shales have a short reaction time, which increases with its hardness. This test also shows the inhibition state of a mud and can therefore be used in mud monitoring and mud-treatment design. The rolling test provides useful information on the dispersion tendencies of a shale-cuttings/mud mixture, and the CEC test provides basic information on the effective clay content of a shale.

This paper discusses techniques used to evaluate shales and muds at the rig site and presents the procedures, results, and parameters that affect each technique. Information concerning a new device for measuring shale swelling and the procedure for reconstituting shale cuttings is given.

Introduction

The standard procedure in drilling operations is to apply knowledge gained from bad experiences to subsequent wells drilled in similar geologic environments. There is no doubt that studies done after wells are drilled provide valuable information in planning for other wells, but they usually are of little value at the well when the problem occurs.

Various solutions have been suggested for dealing with troublesome shales. Kelly[1,2] presented guidelines for choosing drilling fluids for drilling various types of shales. Mondshine[3] and Chenevert[4] developed oil-based drilling fluids that have been used successfully to drill water-sensitive formations. O'Brien and Chenevert,[5] Mondshine[6] and Clark *et al.*[7] developed various polymer/KCl water-based drilling fluids to reduce shale swelling.

At present, the preferred options to counter shale problems at the rig site are raising the drilling-fluid weight and changing the drilling fluid to a balanced-activity mud or to an inhibitive polymer/KCl mud. Limitations of rig-site methods are the lack of quantifiable information about problem-shale behavior and the exact degree of inhibition achieved by the mud on a day-to-day basis.

Shale Instability—Chemical Reactions

Most shales contain chemically active, compacted clays. When the shales are exposed to drilling fluids, the clays adsorb water and swell,[8] producing many drilling problems. There is a current need for rig-site analytical techniques that help to define the type and severity of the shale/mud chemical reaction so that solutions may be found.

Stages of Shale Instability. Before rig-site shale-testing techniques are discussed, it is useful to describe the stages of downhole shale/mud reactions and the resultant problems. The shale's original suction potential is described first, and then the reaction phases (hole closure, hole enlargement, and shale dispersion into the mud) are listed.

Original Shale Conditions. Fig. 1 shows a typical compacted shale before it is drilled. The clay in this shale is only partially hydrated, as evidenced by the presence of only three layers of water between the clay platelets. This relatively dry shale condition provides a high level of a diffusion-type suction pressure within the shale, which, when allowed to operate, produces swelling displacements and rock stresses. Such suction pressures are estimated to be between −5,000 and −10,000 psi [−34.5 and −69.0 MPa].[9] Under such dry conditions the shale is firm and can be drilled like most other formations.

Shale Swelling Into Wellbore. While the dry shale is being drilled, water and ions are free to diffuse into the shale. They are attracted to the clays and are drawn into the shale by the diffusion process, eventually producing rock-swelling stresses. This first stage of hydration, which lasts from 1 to 24 hours, causes the shale to expand into the wellbore (see Fig. 2) and can cause excessive circulating pressures, lost circulation, and stuck drill collars. Water content increases in the shales near the borehole and between the clay platelets, expanding from three to about five layers. As the platelets adsorb the water, their suction pressure diminishes toward equilibrium. Away from the wellbore, the water has not yet advanced; therefore, the water content is still in its native state, with three layers of water between the platelets.

Wellbore Collapse. As the clays adsorb more water, the shale stresses increase until failure occurs and shale cavings are produced. This results in wellbore enlargement (see Fig. 3) and many associated hole problems—e.g., tight hole and stuck collars caused by wedging by cavings, poor hole cleaning, poor logging and cementing conditions, and difficulty returning the drilling assembly to the bottom.

This swelling/collapse process is repeated over and over, and hole enlargement continues, with the fluid advancing farther and farther away from the hole's center. Blakeman[10] displayed such time-related shale alterations on electric logs.

Dispersion of Shale Into Mud. Fig. 3 also shows clay particles that dispersed into the mud. After the shale caves into the hole, the surface of each caving continues to hydrate and "melts" into the mud, releasing the clays, which then become unwanted drilled solids.

It is interesting to note that during these phases of hydration, the clay continually expands and ultimately satisfies its potential to adsorb water.

Rig-Site Shale/Mud Testing

One way to study shale/mud interaction is to build equipment that completely simulates all aspects of the wellbore instability process. This has been done in research laboratories,[11] but such equipment does not lend itself to rig-site evaluation techniques because it is too large and too slow. In this study, we decided to evaluate simplified methods that look at basic shale/mud interactions.

Types of Rig-Site Tests. Two categories of tests were investigated: *direct tests,* which measure the direct interaction of the shale with the drilling mud, and *indirect tests,* which measure the effective clay content of the shale. Table 1 describes each test. Note that tests are available only for the first and third phases of shale swelling. At this time, no rigsite method has been developed for evaluating the collapse (fracture) phase of hole instability. For such analysis, the shear failure of a shale must be measured in triaxial compression tests under laboratory conditions.

Four shales, obtained in cored form, were used in this study: Del Rio, Pierre, Mancos, and Devonian. As Table 2 shows, the shales ranged from the high-clay-content, very soft Del Rio to the low-clay-content, very hard Devonian. All cores were very large

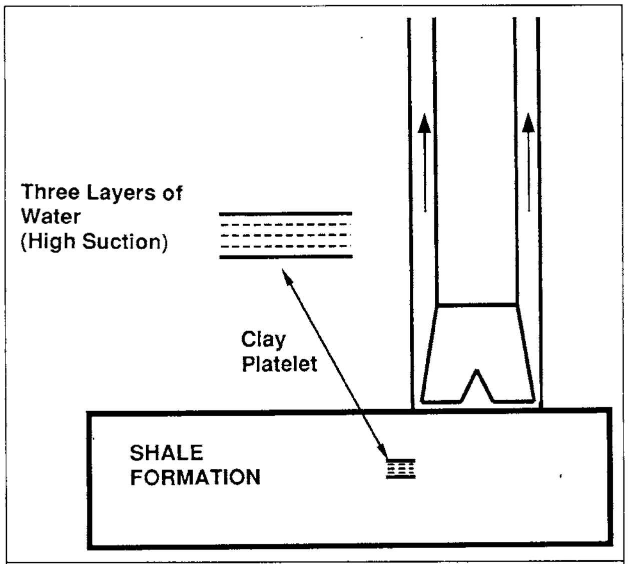

Fig. 1—Shale conditions before drilling.

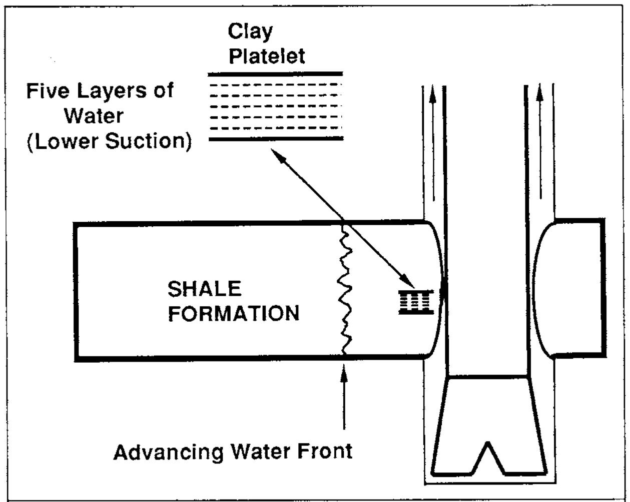

Fig. 2—Shale conditions soon after drilling.

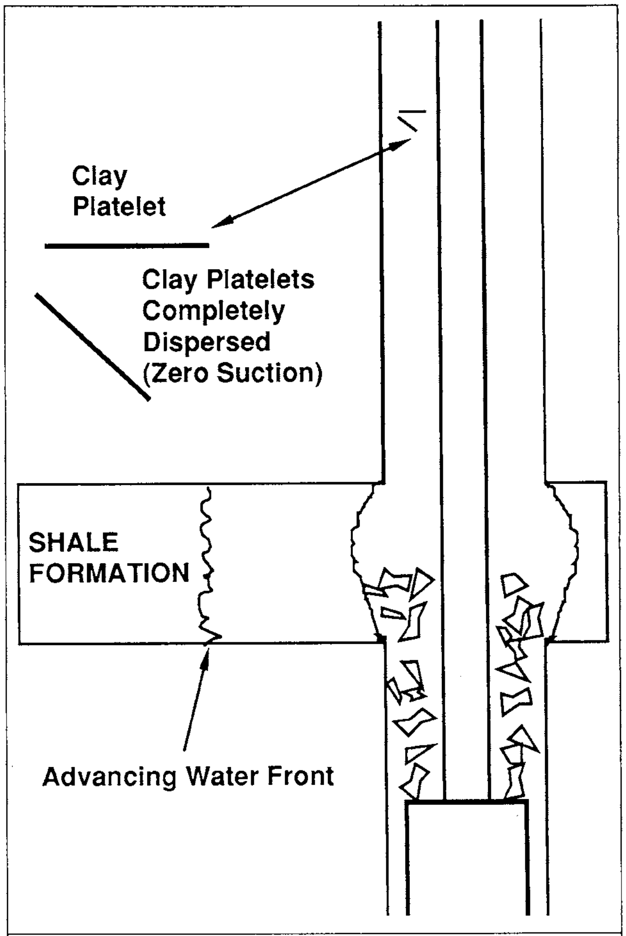

Fig. 3—Shale conditions after caving occurs.

TABLE 1—RIG-SITE TESTS ANALYZED

Test	Measures
Direct	Shale/mud reactions
Swelling-indicator	Shale/mud early-time swelling
Rolling	Shale/mud late-time dispersion
Indirect	Effective clay content of shale
CEC	Number of charge sites on clay
Yield value	Ability of clay in shale to make 15-cp mud
Specific gravity of shale/water suspension	Ability of clays in shale to disperse into colloidal particles
CST	Ability of clays in shale to control filtration

(15 in. [38 cm] in diameter), which allowed multiple samples to be cut and multiple tests to be run from the same rock horizon. This procedure, which used near-identical shale samples, was required for this comparison study to prevent variations between shale samples, which usually happens if shales are taken from different horizons within a given core.

The muds used in this study were deionized water, a low-lime bentonite slurry, a dispersed bentonite suspension, and a polymer/KCl fluid. Table 3 gives the compositions and properties of these fluids. Mud selection objectives were to obtain a range of responses that might be seen under actual drilling conditions and to determine how inhibitive muds affect different shales.

Direct Tests—Shale/Mud Reactions. The two direct tests studied were the swelling and the rolling tests. The swelling test measures the expansion of shale cores in a mud as a function of time, and the rolling test measures the amount of bit cuttings that disperse into a mud after 16 hours of rolling.

Both tests showed that the best results require the use of native shale (i.e., shale pieces whose moisture content has not been significantly altered from its native state in the ground). This was achieved by (1) starting with samples protected from mud and atmospheric alteration, (2) preparing all test specimens with nonaqueous cutting fluids, and (3) keeping the resulting test specimens in sealed containers before testing. In this way, the shale was tested with a representative suction pressure as opposed to very wet shale, which has no suction, or very dry shale, which has abnormally high suction and usually contains many fine cracks.

Swelling Tests. A new rig-site technique to evaluate a shale's swelling tendencies in various muds was developed. The test uses a "swelling indicator" (Fig. 4), which consists of a digital displacement transducer mounted to a core holder that contains shale samples. In operation, the shale specimen ($\frac{1}{2}\times\frac{1}{2}\times1$ in. [$12.7\times12.7\times25.4$ mm]) is fastened between the anvils of the core holder, test fluid is poured into a plastic bag that surrounds the shale, and shale expansion is displayed on the digital displacement transducer and recorded. Displacement values are converted into "swelling percentages" by dividing the displacement values by the original lengths of the samples and multiplying by 100. The displacement indicator is able to measure total displacements of 0.4 in. [1 cm] with a resolution of 0.004 in. [0.01 cm].

TABLE 2—SHALE PROPERTIES TESTED

	Shale			
Description	Del Rio	Pierre	Mancos	Devonian
Location	Austin, TX	Eastern Colorado	Central Utah	Chillicothe, OH
Hardness	Very soft	Soft	Hard	Very hard
Crystalline Composition, %				
Smectite (clay)	11	9	0	0
Illite (clay)	14	20	2	29
Kaolinite (clay)	5	2	0	1
Chlorite-Fe (clay)	0	2	0	3
Calcite	17	1	4	2
Dolomite	0	1	8	5
Pyrite	2	4	1	8
Feldspar-Na	0	9	2	3
Feldspar-K	2	9	12	2
Quartz	49	43	71	47

TABLE 3—COMPOSITION AND PROPERTIES OF DRILLING FLUIDS USED

		Fluid Properties				
Drilling Fluid Types	Chemical Composition	μ_p	τ_y	pH*	V_f	KCl (ppm)
Water	Deionized	1	0	7.0	—	—
Low-lime bentonite slurry	20 ppb bentonite + 0.5 ppb lime	7	11	7.2	23	—
Dispersed bentonite suspension	20 ppb bentonite + 2 ppb chrome lignosulfate	14	6	9.5	20	—
Polymer/KCl	10 ppb bentonite + 0.5 ppb xanthan polymer + 10 ppb KCl	16	20	10.5	>40	28,000

*pH was controlled with NaOH

Ideally, the native shale samples being drilled should be placed in contact with the currently used mud. This can seldom be done, however, because of the unavailability of such shales. Other options are to use test specimens of similar native shale cut from cores or to use recompacted shale pellets made from drilled cuttings. Both approaches are discussed, but use of test specimens of similar native shale is preferred because availability is not a major problem, excellent results can be obtained, and rig-site procedures are minimized.

Swelling Tests That Use Native Shales. Fig. 5 shows examples from swelling tests that use hard- and soft-core-cut samples of native shale placed in the swelling indicator. The hard shale swells to a total value of 2% after about 400 minutes and remains intact, and the soft shale crumbles (fails) in 10 minutes after it swells to 0.75%.

One objective of this study was to develop a way to classify shales and shale/mud systems according to their reactivity (swelling rate) in various fluids. A swelling value of 0.5% was selected as a reference point. The time for a shale to reach 0.5% elongation, the shale swelling time (t_{ss}), is recorded and then compared to the time in the reference test. The reference fluid is normally fresh water. The low value of 0.5% swelling was chosen to minimize the time required for testing and to allow for the testing of very soft shales, which seldom swell beyond 0.75% before failure.

In Fig. 5, the soft and hard shales have t_{ss} values of 7 and 20 minutes, respectively. Figs. 6 through 11 show swelling results for the 24 shale/mud tests, and Tables 4 and 5 list the t_{ss} data.

As Table 4 shows, a definite pattern is observed, with t_{ss} being shorter for the high-clay-content, soft shales (Del Rio and Pierre) and longer for the low-clay-content, hard shales (Mancos and Devonian). Table 4 also shows the effect of exposing shales to various inhibitive muds. Definite differences in t_{ss} are observed for the different muds. From the data shown, one would expect hole stability to increase the most for those shales that use a polymer/KCl system. This observation is consistent with reported field results.$^{5-7}$

The data in Table 4 can also be used for "time classification" of shales. These data indicate that hole enlargement would occur

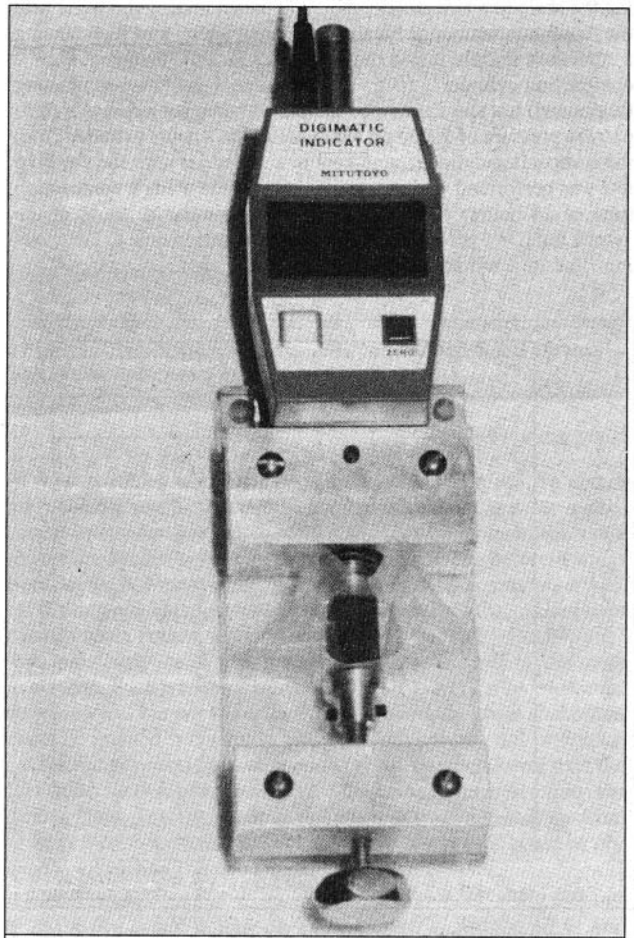

Fig. 4—Shale/fluid swelling indicator.

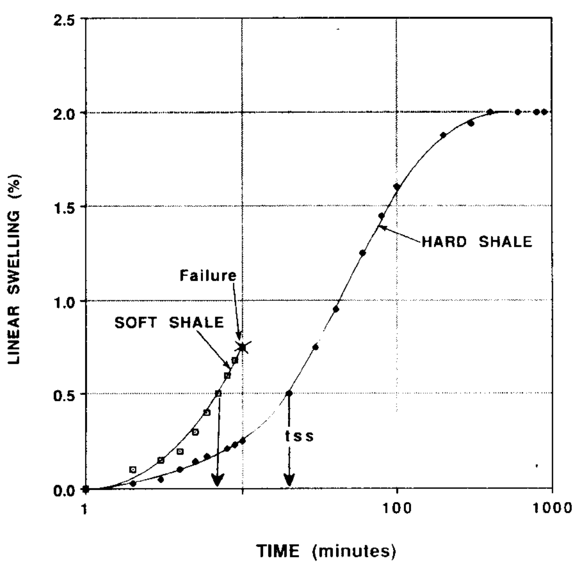

Fig. 5—Typical swelling-vs.-time response for soft and hard shales immersed in water.

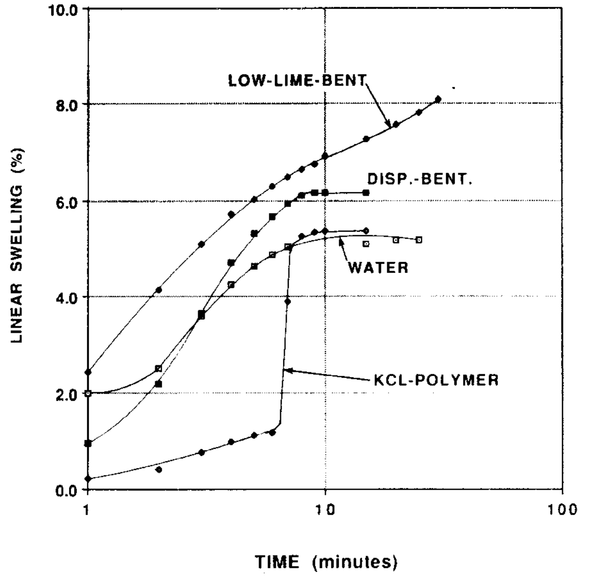

Fig. 6—Swelling-vs.-time curves for native Del Rio shale immersed in various fluids.

soonest in the Del Rio shale, where the $t_{ss} < 1$ minute for water, and latest in the Devonian shale, where the $t_{ss} > 400$ minutes for water.

Swelling Tests That Use Compacted Shales. In certain cases it may be desirable to use cuttings from the shale shaker to run shale/mud swelling tests. Therefore, equipment that compacted drilled shale chips into test specimens was used.

The reconstituted compacted-shale samples were made by grinding the shale to a size smaller than 200 mesh, mixing the shale with the "optimum amount of water" (defined later), and then placing a sufficient sample inside the ½-in. [12.7-mm] -diameter Parr™ compaction cylinder[12] (Fig. 12) to make a 1-in. [24.4-mm] -long (undrained) test specimen. The sample was then subjected to a compaction pressure of 5,000 psi [34.5 MPa] for 1 hour, extruded from the compaction cylinder, and kept in a sealed jar until the swelling test was performed. Other samples were made using a compaction time of 24 hours,[13] but the results were similar to those of the 1-hour tests. We recommend a 1-hour compaction time to keep testing time to a minimum.

The optimum amount of water used in the compaction test is the amount that produces the maximum-density test specimen. For a given shale, this value must be determined experimentally. In our tests, the Pierre and Devonian shales had a value of about 8% by weight for their optimum amounts of water (see Fig. 13). If the optimum amount is not used, the sample will be either too dry, thus crumbling when removed from the compaction cell, or too wet, thus having no swelling tendencies. Note that this compaction method produces "undrained" pellets; compaction cells, which have filtration ports, produce "drained" pellets.

Figs. 10 and 11 and Table 5 show the results of swelling tests run with the reconstituted compacted-shale specimens. Although these swelling tests did not give t_{ss} values identical to those obtained from tests in which native shale was used (the t_{ss} values were much lower in the reconstituted shale tests), the ordering of shale/mud reaction times was similar. These results suggest that, when necessary, reconstituted compacted-shale pellets can be used to select drilling mud. This method has three major drawbacks: (1) it takes about 4 hours to make one test pellet; (2) the compacted-shale pellets crush quickly and easily because they have no cementation; (3) the pellet's suction pressure is probably either too high

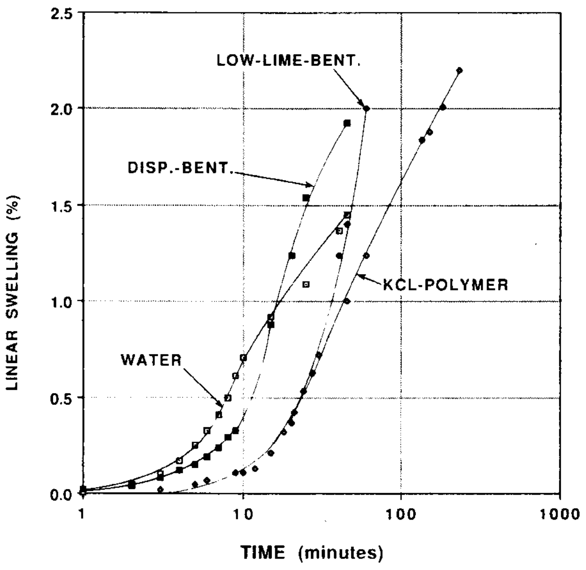

Fig. 7—Swelling-vs.-time curves for native Pierre shale immersed in various fluids.

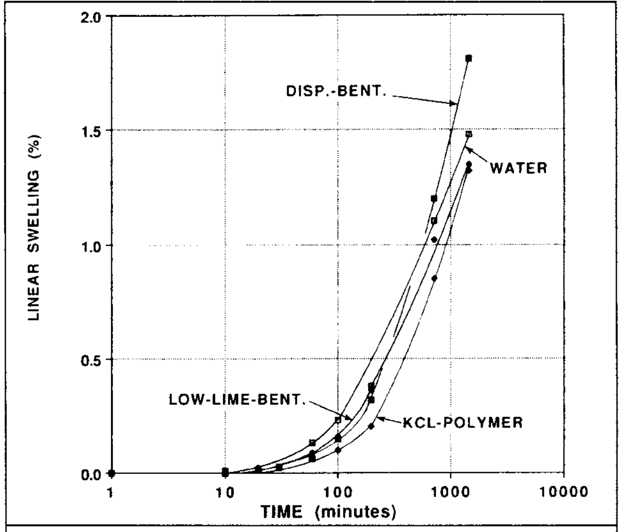

Fig. 8—Swelling-vs.-time curves for native Mancos shale immersed in various fluids.

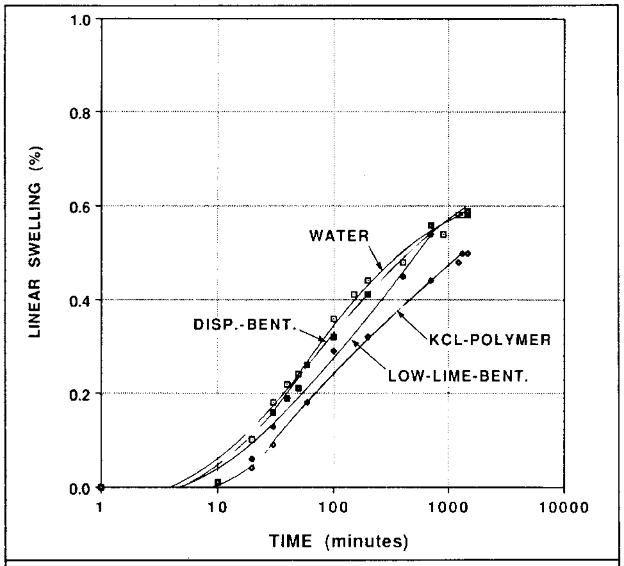

Fig. 9—Swelling-vs.-time curves for native Devonian shale immersed in various fluids.

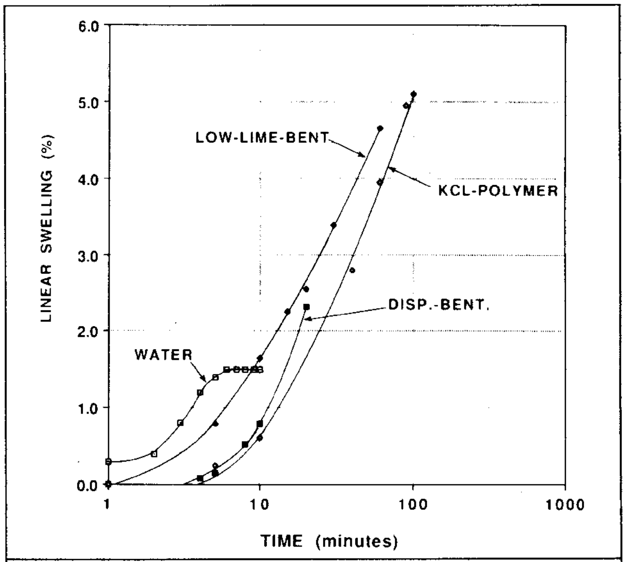

Fig. 10—Swelling-vs.-time curves for reconstituted Pierre shale immersed in various fluids.

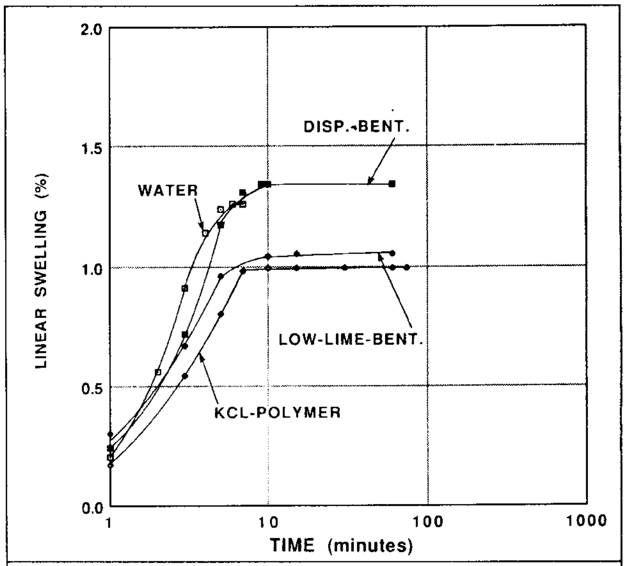

Fig. 11—Swelling-vs.-time curves for reconstituted Devonian shale immersed in various fluids.

or too low because it is determined by the stress used in the compaction cell and not by the earth stresses encountered in the well.

The main advantage of the shale swelling test is its ability to measure the reaction rate of high-suction shale in contact with any mud being used. Mud viscosity does not influence this test, and results can be obtained for highly reactive shales in <1 hour. The main disadvantage of the test is the necessity to use similar shale rather than wellsite or compacted shale. Although this test reflects only what is happening during the first stage of the swelling/failure process, it is very useful because control of early-time swelling would eliminate the other two stages.

Shale Rolling Tests. Dispersion of shale cuttings into the mud during a shale rolling test is a measure of a shale's hardness and reactivity to certain test muds. It provides a direct method for evaluating dispersion tendencies of shales during their final stage of expansion.

This test uses the following procedure. Twenty grams of 4/8-mesh-size shale cuttings are placed in a 400-mL aging cell that is partially filled with 350 mL of mud and allowed to roll at 50 rev/min for 16 hours at 150°F [65.6°C]. The mixture is then poured through a 200-mesh screen, and the amount of shale (measured in grams) that passes through the screen (the "dispersed shale") is determined. The percentage of shale dispersed into the mud is determined by dividing the amount of shale that passes through the 200-mesh screen by the total amount of shale introduced into the shale rolling cell. The quotient is then multiplied by 100.

The results obtained in this study (Table 6) show that the softer shales have the highest amount of dispersion and that the more inhibitive muds reduce dispersion tendencies. We also noticed that the more-viscous muds had a lower dispersion rate. High-viscosity fluids minimized the tumbling agitation of the particles, producing results that could not be compared to low-viscosity muds. To study the viscosity effect, the low-lime bentonite slurry was chosen, and the tests were repeated with muds that had higher apparent viscosities. Viscosities were increased by the addition of xanthan polymer. As expected, the dispersion rate decreased as the apparent viscosity of the mud increased from values of 10 to 23 to 38 cp [10 to 23 to 38 mPa·s]. We recognized that the xanthan polymer has an inhibiting component. In the concentration range studied, however, the resulting effect was minimal compared with the viscosity effect.

In other tests,[13] three different mesh-size particles of each shale were used to study the dispersion of such cuttings for each mud. The sizes were 4/8, 4/20, and 4/100-mesh. Tests run with the 4/20 mesh consisted of equal parts of 4/8- and 8/20-mesh particles; the 4/100-mesh tests consisted of an equal amount of 4/8-, 8/20-, and 20/100-size particles. In these tests, the dispersion value increased as finer particles were included in the test. Therefore, to obtain reproducible results that can be compared to other tests, it is necessary to standardize the particle size. If cuttings from the shale shaker are used, they should be sized with screens before testing. Because the 4/8-mesh-size range most adequately represents a typical drilling environment and gives meaningful results, it should be used in shale rolling tests whenever possible.

As previously mentioned, it was necessary to use native-state shale in all tests. Such a requirement could be achieved for the preserved core samples, but not for drilled cuttings from the shale shaker because no method is currently available for applying this principle. Such cuttings normally have suction pressures much lower than the formation suction pressure because they adsorb moisture from the drilling fluid. Tests were run in this study with drilled cuttings from wells drilled in south Texas, but only poor test results could be obtained with these "water-logged" cuttings.

The rolling test is useful for determining how fast shale cuttings disperse into a given mud. It is simple to run, and multiple tests can be run simultaneously. However, the test usually take 16 to 24 hours.

TABLE 4—SHALE SWELLING TIMES FOR NATIVE SHALES IN VARIOUS MUDS

Shale	Mud Type	t_{ss} (time to reach 0.5% swelling) (minutes)	Swelling relative to water (%)
Del Rio	Water	<1	—
	Dispersed bentonite	<1	—
	Low-lime bentonite	<1	—
	Polymer/KCl	3	—
Pierre	Water	8	100
	Dispersed bentonite	11	73
	Low-lime bentonite	22	36
	Polymer/KCl	23	35
Mancos	Water	240	100
	Dispersed bentonite	270	89
	Low-lime bentonite	280	86
	Polymer/KCl	450	53
Devonian	Water	440	100
	Dispersed bentonite	440	100
	Low-lime bentonite	500	88
	Polymer/KCl	1,300	34

TABLE 5—SHALE SWELLING TIMES FOR COMPACTED SHALES IN VARIOUS MUDS

Compacted Shale	Mud Type	t_{ss} (time to reach 0.5% swelling) (minutes)	Swelling relative to water (%)
Pierre	Water	2.2	100
	Dispersed bentonite	7	31
	Low-lime bentonite	3	73
	Polymer/KCl	9	24
Devonian	Water	1.9	100
	Dispersed bentonite	2.4	80
	Low-lime bentonite	2.3	83
	Polymer/KCl	2.8	68

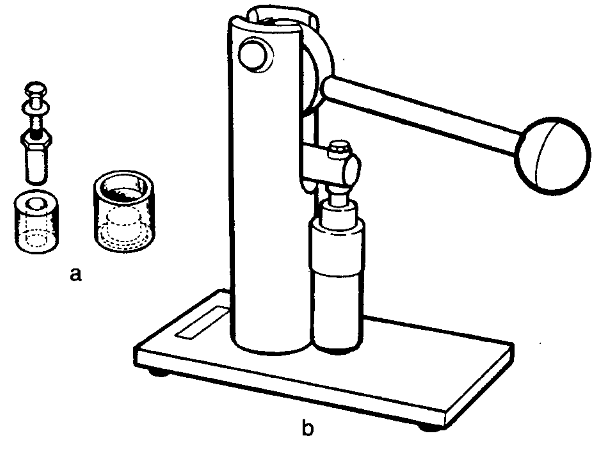

Fig. 12—Shale compaction cylinder (a) and mechanical press (b).

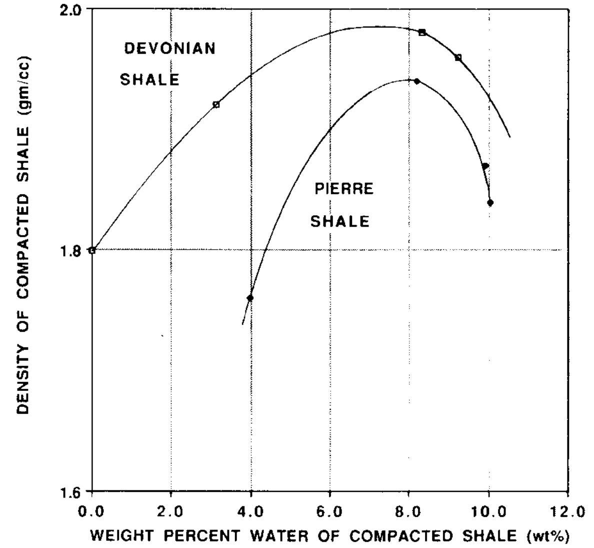

Fig. 13—Density-vs.-weight-percent water for Pierre and Devonian shales after compaction for 1 hr.

One major limitation of this test is that it displays the swelling tendencies of shale for only the final stages of expansion. It has been shown that certain mud chemicals—e.g., polymers,[5] which prove useful in this test for reducing dispersion rate when the suction pressures are no more than −10 psi [−69 kPa]—are not adequate for reducing the early stages of shale swelling when suction pressures ≥ −5,000 psi [−34.5 MPa].

TABLE 6—SHALE ROLLING TESTS, DISPERSABILITY PERCENTAGE OF SHALES FOR VARIOUS MUDS

Drilling Fluid Type	Shale Del Rio	 Pierre	 Mancos	 Devonian
Water	92.0	84.0	58.0	2.0
Dispersed bentonite suspension	27.0	6.0	3.0	1.0
Polymer/KCl	—	10.0	3.0	1.0
Low-lime bentonite slurry, AV* = 10	37.0	11.5	5.0	0.8
Low-lime bentonite slurry + 0.5 ppb xanthan polymer, AV = 23	28.0	6.5	2.0	0.2
Low-lime bentonite slurry + 2 ppb xanthan polymer, AV = 38	26.5	5.8	1.5	0.0

*AV = apparent viscosity.

Another problem is that changes in the test conditions—e.g., time of rolling, temperature, rolling rate, shale chip size, and mud viscosity—can determine the outcome.

We recommend that the shale rolling test be standardized by using (1) a relatively constant viscosity (preferably 20 to 40 cp [20 to 40 mPa·s]), (2) 4/8-mesh-size particles, (3) a temperature of 150°F [65.6°C], (4) rolling rates of 50 rev/min, and (5) a 16-hour rolling time.

Indirect Tests—Effective Clay Content. Four tests were analyzed for their ability to determine the effective clay content of a given shale. These tests do not define the type of clay present (e.g., montmorillonite, illite, chlorite, etc).

Each test uses finely ground shale (<200 mesh) mixed with water and focuses on different characteristics of the shale/water mixture, including CEC, yield value, specific gravity of shale/water suspension, and capillary suction time (CST).

Note that these tests do not consider the downhole wetness of the clay and therefore do not include the level of suction pressure that a shale may have in the ground. It is conceivable that two shales could have identical effective-clay-content values, yet respond downhole in a very different manner if, for example, one is very wet and the other is very dry.

The following sections give the basic information for each test. Additional information is available in the literature.[13]

CEC Test. Cation exchange, a surface phenomenon, occurs on the charged surfaces of clay minerals. The reactivity of a clay mineral depends on its CEC, Q. Q is a measurement of the milliequivalent weight of the exchanging cations per 100 grams of material. Jones[14] introduced a dye adsorption method called the methylene blue test for the determination of the bentonite (clay) content of drilling fluids. This method is fast and easy to perform. Some researchers[15-17] have used this method to establish the mineralogical types of shales and to estimate the reactive clay content of shales. This work attempts to extend the methylene blue test to the systematic determination of the CEC of shales.

In this test, a slurry is made with <200-mesh shale cuttings and water, and the CEC is measured with standard mud testing procedures as described in API *RP 13B*.[18]

In other tests, the original particle sizes were varied and various heating and stirring techniques were investigated.[13] From such studies it was concluded that the preferred manner of testing should include the use of particles smaller than 200 mesh and that the shale/water slurry should be stirred for 15 minutes in a multimixer.

TABLE 7—EFFECTIVE CLAY CONTENT OF SHALES DETERMINED WITH VARIOUS TESTS

Shale	Test Type CEC (meq/100 g)	 Yield Value (bbl/ton)	 Colloidal Content (%)	 CST (seconds)
Del Rio	23.3	18.6	52	120
Pierre	17.5	12.5	22	78
Mancos	6.5	9.6	7	38
Devonian	5.6	9.2	2	56

Table 7 shows results obtained for the four shales studied. These results show that the effective clay content of a given shale can be determined with Q just as one would determine the effective clay content of a drilling fluid. The results also show that shales should first be ground to <200-mesh particle sizes, and stirred and heated when the slurry to be tested is made.

Yield-Value Test. In drilling-mud studies, the ability of a commercial clay to increase the water viscosity is measured in terms of its hydration capacity, i.e., yield value. The yield value of clay is the number of barrels of a 15-cp (15-mPa·s) drilling fluid that can be obtained from 1 ton [0.9 Mg] of dry clay. For commercial bentonite, the yield value is about 100 bbl [15.9 m^3]. Because shales contain clay minerals, the yield value should be a measure of their hydration tendencies.

The yield values of the four shales were measured with standard procedures[19] and are presented in Table 7. As shown, the shales with the higher clay content had higher yield values.

No equipment other than the standard mud test equipment is needed to run this test, and results are as useful as the Q-test results. A drawback, however, is the length of time (4 hours) necessary to complete the test.

Specific Gravity of Shale/Water Suspension Test. This test, which uses a hydrometer to determine the specific gravity of shale/water mixtures, was developed in the soil science industry.[20,21] The method is based on the close relationship between the colloidal content (clay content) of a soil and the percentage of a sample that stays in suspension in water at the end of 15 minutes.

Table 7 presents the results obtained for the four shales. As shown, the colloidal content is higher for those shales that have a higher effective clay content.

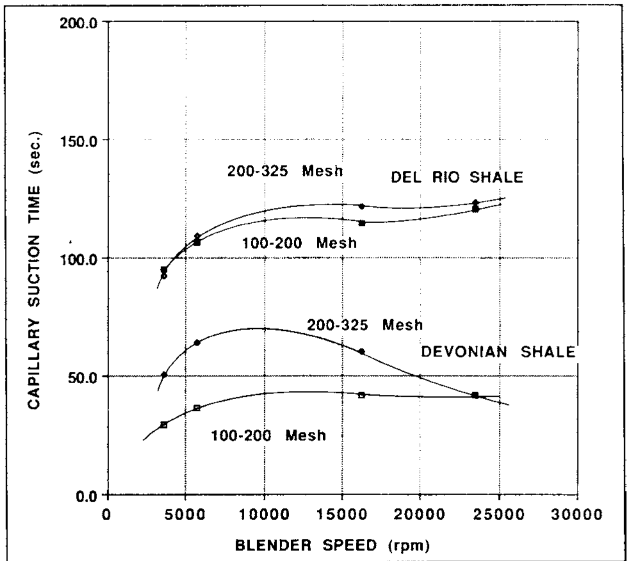

Fig. 14—CST as a function of particle size and blender speed for Del Rio and Devonian shales at a solids concentration of 52.5 lbm/bbl.

This test provides results that correlate very well with those of the Q test, and it conceivably could replace the Q test. The only disadvantage is that it works well for the soft, high-clay-content shales, but is rather insensitive to the hard, low-clay-content shales.

CST Test. Recently, the CST, t_{cs},[22-24] test was introduced to characterize shales and to study shale dispersion/filtration properties.

With commercially available equipment,[25] tests were run while the speed of the blender, the original particle size, and the shale/water ratio were varied. Fig. 14 shows the results obtained for the Del Rio and Devonian shales for concentrations of 52.5 g of shale per 350 mL of water. As shown, the t_{cs} value is a nonlinear relationship with shear rate; as the speed of the blender is increased, t_{cs} increases if more dispersion occurs and decreases if aggregation occurs. Fig. 14 also shows the effect of starting with different particle sizes (e.g., either 100/200- or 200/325-mesh).

Table 7 lists t_{cs} values for the four shales. For these tests, the 100/200-mesh-size particles were used and the blender was operated at 23,500 rev/min.

In other tests,[13] the shale/water ratio was varied, and, as expected, the t_{cs} increased as the solids content increased.

One disadvantage of this test is that it essentially measures the potential for the shale to produce filtration control, a parameter not directly related to shale inhibition. For a specific mud, however, filtration characteristics of the mixture are often related to the effective clay content of the shale; therefore, under restricted conditions, this test can be used as an indicator.

From this series of tests, we concluded that it is imperative that the t_{cs} test be standardized. Results from this test can be compared only if the same mixing speed, original particle size, general mud type, and shale/water concentration are used. The salinity of the water in the mixture should also be fixed because salinity changes cause clay flocculation, which has a large effect on the t_{cs}.[23] Further research is required, however, before we can recommend standardized conditions that will produce useful results.

Conclusions and Recommendations

1. Rig-site measurements of shale/mud inhibition can be determined with the swelling indicator.

2. Of the seven tests studied, only the swelling-indicator test can be used to define the early-time swelling properties of a shale.

3. The rolling test can be used to describe the dispersion tendencies of a shale into a mud, but results are highly dependent on test methods, which need to be standardized.

4. The effective clay content of a shale can best be described with the CEC test. Other tests that may be useful include the yield-value, specific-gravity, and CST tests.

5. Compaction methods that use optimum-water concepts can be used to develop shale test specimens from drilled cuttings.

Nomenclature

Q = cation exchange capacity, meq/100 g
t_{cs} = capillary suction time, seconds
t_{ss} = shale swelling time (time for shale to swell ½%), minutes
V_f = API water loss, mL
μ_p = plastic viscosity, cp [mPa·s]
τ_y = yield point, lbf/100 ft^2 [Pa]

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References

1. Kelly, J. Jr.: "Drilling Problem Shales," *Oil & Gas J.* (June 3, 1968) 67-70.
2. Kelly, J. Jr.: "A New Look at Troublesome Shales—Part 2," *Oil & Gas J.* (June 10, 1968) 94-112.
3. Mondshine, T.C.: "New Technique Determines Oil-Mud Salinity Needs in Shale Drilling," *Oil & Gas J.* (July 14, 1969) 70-75.
4. Chenevert, M.E.: "Shale Control with Balanced-Activity Oil-Continuous Muds," *JPT* (Oct. 1970) 1309-16; *Trans.*, AIME, **249.**
5. O'Brien, D.E. and Chenevert, M.E.: "Stabilizing Sensitive Shales With Inhibited, Potassium-Based Drilling Fluids," *JPT* (Sept. 1973) 1089-1100; *Trans.*, AIME, **255.**
6. Mondshine, T.C.: "Tests Show Potassium Mud Versatility," *Oil & Gas J.* (April 22, 1974) 120-30.
7. Clark, R.K. *et al.*: "Polyacrylamide/Potassium-Chloride Mud for Drilling Water-Sensitive Shales," *JPT* (June 1976) 719-27; *Trans.*, AIME, **261.**
8. Chenevert, M.E.: "Shale Alteration by Water Adsorption," *JPT* (Sept. 1970) 1141-47.
9. van Olphen, H.: "Compaction of Clay Sediments in the Range of Molecular Particle Distances," *Proc.*, 11th Natl. Conference on Clay and Clay Minerals, Ottawa (Aug. 13-17, 1962) **13,** 184-86.
10. Blakeman, E.R.: "A Case Study of the Effect of Shale Alteration on Sonic Transit Times," *Proc.*, SPWLA 23rd Annual Logging Symposium, Corpus Christi (July 6-9, 1982) **11.**
11. Darley, H.C.H.: "A Laboratory Investigation of Borehole Stability," *JPT* (July 1969) 883-92; *Trans.*, AIME, **246.**
12. "Pellet Press," Parr Instrument Co., Moline, IL.
13. Osisanya, S.O. and Chenevert, M.E.: "Rig-Site Shale Evaluation Technique for Control of Shale-Related Wellbore Instability Problems," paper SPE 16054 presented at the 1987 SPE/IADC Drilling Conference, New Orleans, March 15-18.
14. Jones, F.O. Jr.: "New Fast, Accurate Test Measurement of Bentonite in Mud," *Oil & Gas J.* (June 1, 1964) 76-78.
15. Anderson, D.B. and Edwards, C.D.: "Fluid Development for Drilling Sloughing and Heaving Shales," *Pet. Eng. Intl.* (Sept. 1977) 105-18.
16. Mondshine, T.C.: "New Fast Drilling Muds Also Provide Hole Stability," *Oil & Gas J.* (March 21, 1966) 84-90.
17. Anderson, D.B. and Estes, J.C.: "Review of Low Solids Mud Control Gives Insights," *World Oil* (April 1981) 79-85.
18. *RP 13B, Recommended Practice for Standard Procedure for Field Testing Drilling Fluids,* 11th edition, API, Dallas, TX (May 1985) 17-18.
19. McCray, A.W. and Cole, F.W.: "Oil Well Drilling Technology," U. of Oklahoma Press, Norman, OK (1979) 116-17.
20. Bouvoucos, G.J.: "Directions for Determining the Colloidal Material of Soils by the Hydrometer Method," *Science* (July 1, 1927) **66.**
21. Holmes, H.N.: *Laboratory Manual of Colloid Chemistry,* John Wiley and Sons Inc., New York City (1934) 176-79.
22. Wilcox, R.D. and Lauzon, R.V.: "New Method Helps Troublesome Shale," *Drilling Contractor* (Feb. 1982) 36-42.
23. Wilcox, R. and Fisk, J.: "Tests Show Shale Behavior, Aid Well Planning," *Oil & Gas J.* (Sept. 12, 1983) 106-25.
24. Wilcox, R.D., Fisk, J.V. Jr., and Corbett, G.E.: "Filtration Method Characterizes Dispersive Properties of Shales," *SPEDE* (June 1987) 149-58; *Trans.*, AIME, **283.**
25. "The Capillary Suction Time Instrument," Venture Innovations Inc., Lafayette, LA.

SI Metric Conversion Factors

cp × 1.0* E−03 = Pa·s
in.^{3} × 1.638 706 E+01 = cm^3
lbm/bbl × 2.853 010 E+00 = kg/m^3

*Conversion factor is exact.

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