

## **PETROLEUM ENGINEERING**

### **Testing of Saudi Shales for Potential Use in Drilling Fluids**

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(Received 27/2/1991; Accepted for Publication 30/6/1991)

**Abstract.** This paper presents the results of rheological, electrochemical and filtration analyses of Umm-er-Radhuma shales in Saudi Arabia. The analyses indicate that these shales could be used as a basic constituent of drilling fluids. A preliminary assessment of the raw material future requirements in the drilling operations in Saudi Arabia is made.

The mineralogical and chemical analyses of Umm-er-Radhuma shales showed the presence of palygorskite in these sediments. These shales consisted of more than 95% clay size particles most of which were less than 0.2  $\mu\text{m}$  in size. The rheological behavior of palygorskite based fluids have been studied with and without the addition of chlorides and/or hydroxides of Na, K, Ca and Mg. The changes in the rheological properties have been correlated with the mineralogy of the used clays.

It is believed that Saudi Arabia will invest huge sums of money to increase its oil production capacity in order to meet the expected oil demand increase in the 90s. Drilling activities will consume a big share of the investment. It is found that the use of Umm er Radhuma natural resources in the drilling of oil and water wells in Saudi Arabia will save millions of dollars that otherwise would have to be spent on importing the raw materials from elsewhere.

#### **Introduction**

Bentonite and palygorskite are widely used as mud constituents in the drilling operations. Other industrial and commercial applications also exist. Although, the use of these clays in applications other than drilling activities might represent a big share of the total consumption in Saudi Arabia, this paper's purpose is achieved by only looking at their consumption in the drilling activities. Unfortunately, accurate data of clay consumption in Saudi Arabia are not available. However, our personal communication with concerned authorities indicated that the present consumption in the

drilling operations of oil, gas and water alone can reach up to 70 thousand tons a year [1]. Almost all locally consumed clays are imported. In the 1990 dollars, the Cargo Insurance Freight (CIF) cost is 85 dollars per ton. A simple calculation shows that the present cost of using clays in the local drilling industry is about 6 million dollars per year.

#### Historical and Future Drilling Activities in Saudi Arabia

Table 1 is a historical list of the number of wells completed and footage drilled in Saudi Arabia between 1977 and 1989. The historical data representing total number of wells drilled and total footage in the same period as well as projected figures till year 2000 are shown in Figs 1 and 2. It is clearly indicated by these figures that the historical drilling activities can be effectively correlated with the historical international crude oil prices during the period 1977-88. It is this fact that would be used to project the future trend of the drilling activities in Saudi Arabia.

Table 1. Historical drilling activities in Saudi Arabia

Year	Number of wells completed	Total drilled Footage
1977	177	1,216,360
1978	126	891,856
1979	111	772,901
1980	185	1,244,927
1981	182	1,277,301
1982	166	1,203,302
1983	190	1,433,317
1984	107	854,295
1985	95	692,856
1986	28	214,318
1987	21	175,098
1988	17	133,585
1989*	23	184,525

Source: OAPEC data base

\* Estimated

World crude oil demand is rising gradually and this trend is expected to continue in the future. Oil supply from the non-OPEC and from OPEC members other than the Arabian Gulf countries is reaching its maximum or decreasing. These factors, among others, are calling for an increase for the Saudi oil in the future. A huge

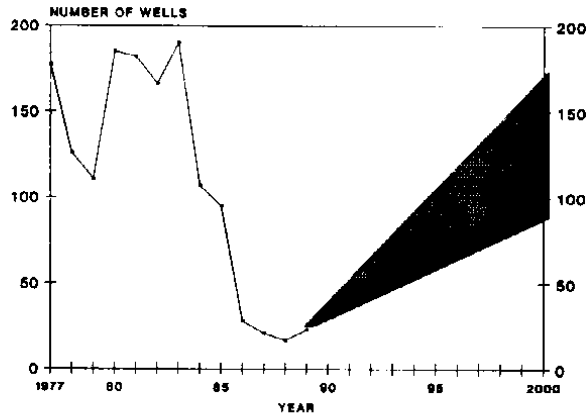


Fig. 1. Drilled & projected no. of wells in K.S.A. (1977-2000)

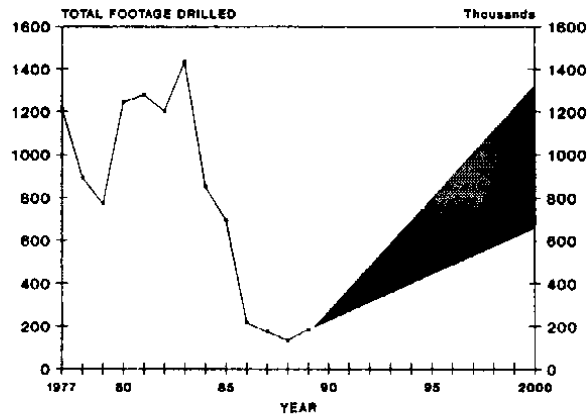


Fig. 2. Drilled and projected footage in K.S.A. (1977-2000)

investment program designed to restore Saudi production capacity to 10 million barrels per day is on its way [2]. This major project is also aimed to maintain the position of Saudi Arabia as the OPEC biggest producer and the world exporting leader. A previously unexplored area south-east of Riyadh is considered to be a major future expansion for drilling operations.

Based on the facts mentioned above we attempted to project the future trend of the drilling activities in Saudi Arabia. This attempt is schematically shown in Figs 1 and 2. It is estimated that the average yearly growth of these activities until the year 2000 is 16 percent for the base case and 12 and 20 percent for the low and high scenarios, respectively.

#### **Commercial Prospective of Umm er Radhuma Clay**

It is uncertain at this stage to speculate about the commercial feasibility of Umm er Radhuma clay. However, the size of the formation and the clay quantities that can be found in the outcrop warrant a serious consideration to pursue an extensive feasibility study. Other factors that justify such a project are the bright future for drilling activities as shown earlier and the ever increasing clay consumption in other applications. A major market for Saudi clay can also be found in the neighboring Gulf Cooperation Council (GCC) countries. It is expected that the drilling activities in the GCC countries are to follow a similar trend as in Saudi Arabia. Exporting Saudi clay to the international market must be taken into consideration to play a major role in any serious Saudi clay industry. Finally, we would like to stress the fact that, this subject must be looked at seriously by the drilling industry in the Kingdom as it will save the country a good sum of hard currency.

#### **Geological Background**

Geologically, the Arabian Peninsula is divided into two structural provinces. The western province, known as the Arabian Shield, consists of igneous and metamorphic rocks. The eastern part, known as the Arabian Shelf, consists of a sequence of continental and shallow water marine sediments ranging in age from Cambrian to Pliocene. Palaeozoic, Mesozoic and lower tertiary strata are exposed in the center of Saudi Arabia forming a great curved belt bordering the shield [3].

The clay under investigation belongs to Umm er Radhuma formation. It forms a wide belt of 50-100 km extending more than 1200 km from the northern boarder of Saudi Arabia to Wadi Al-Dawassir south. Fig. 3 is a schematic presentation of the formation location and extension in Saudi Arabia [4]. In many places along its extension, formation rocks can not be identified because of the thick Neogene sediments and desert sand which go back to the quaternary era. It is worthwhile to mention that the formation extends south and east below the Empty Quarter sands which outcrops back at the boundaries of the huge desert [5]. Thickness of Umm er Radhuma formation reaches up to 240 meters (790 ft) at its ideal section in Hafer Al Batin north east of Saudi Arabia. Its thickness increases east and south to 435 meters (1430 ft) in the Empty Quarter basin and goes up to 500 meters (1640 ft) north of Hofouf. The formation thickness decreases down. The exposures of the Umm er Radhuma formation forms a gently undulating but rough surface with low isolated hills and benches

[6]. The formation consists of a repetitional series of calcitic and dolomitic limestone. At the bottom of Umm er Radhuma and top of Aruma formations, a light yellow fissile shale interrelated occasionally with thin bed of gypsum is exposed near Khurays, eastern Saudi Arabia as shown in Fig. 4. The top of the formation is composed of marl and shale near the central and southern provinces of Saudi Arabia.

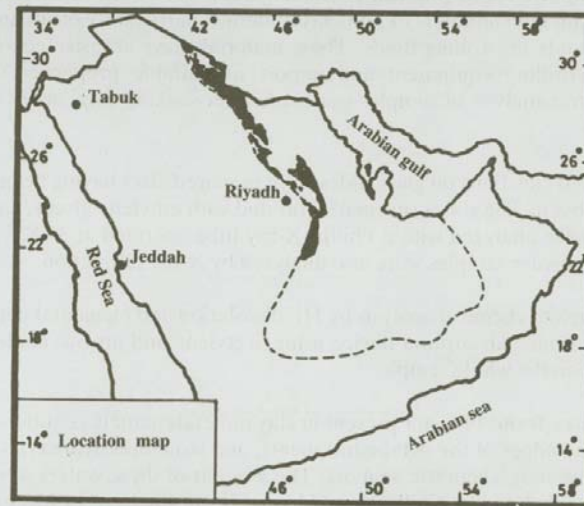


Fig. 3. Umm er Radhuma formation outcrops and extension



Fig. 4. Umm er Radhuma shales outcropping near Khurays

### Experimental

A thorough characterization of Umm er radhuma shales was carried out by physical, mineralogical, chemical and thermogravimetric analyses.

The importance of physical characterization goes back to the fact that clays which contain high amounts of non-clay minerals, particularly of silt and sand sizes are not suitable for drilling fluids. These materials have abrasive action on pumps and other drilling equipment and import undesirable properties to muds. A granulometric analysis of samples was made after soaking clays in hot water for 24 hours.

Oriented clay films on glass slides were prepared after having been dried at 40-50°C in an oven. The slides (normal, saturated with ethylene glycol, and heated up to 550°C) were analyzed with a Philips X-ray tube operated at 35 KV and 15 mA. Untreated powder samples were also analyzed by X-ray diffraction.

A complete chemical analysis by HF dissolution and elemental determinations by AA775 atomic absorption device using acetylene and nitrous oxide gases were carried out on the whole sample.

The three forms of water present in clay minerals namely zeolitic water, bound water (at the edges of the octahedral sheet), and structural hydroxyles were determined by thermogravimetric analysis. The amount of these waters were compared with those calculated by Caillere and Henin [7], on the basis of ideal palygorskite structures.

All rheological properties were tested using the standard devices offered by courtesy of Baroid Petroleum Services.

### Technical Evaluation Results and Discussion

The granulometric analysis showed that, the samples from Umm er Radhuma shales are characterized by their extreme fineness. They virtually contain no significant sand or silt fractions. More than 95% of the constituting grains have diameters less than 2  $\mu\text{m}$ .

The X-ray diffraction patterns for Umm er Radhuma formation (Fig. 5) proved that, these shales are composed exclusively of palygorskite mineral. The diffractograms showed peaks at 10.46, 6.34, 5.40, 4.49, 4.13, 3.69, 3.18 and 2.59 Å, almost identical to those given by the Joint Committee on Powder Diffraction Standards to playgorskite. In some cases, it is believed by some investigators that palygorskite is invariably associated with montmorillonite by weathering [8] or by addition of mag-

nesium [9, pp. 271-293]. Although, none of these transformations is investigated in the studied samples, palygorskite may be altered to montmorillonite under hydrothermal conditions when drilling in high temperature wells. This alteration will have negative effect on the rheological properties of suspension if salt water is used.

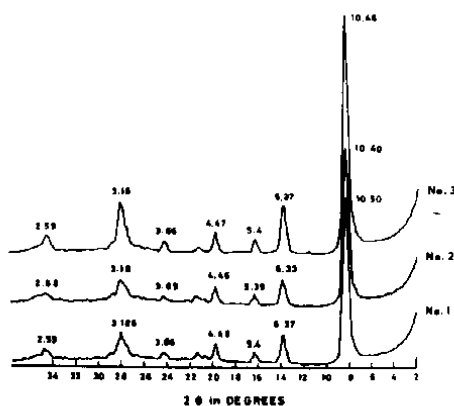


Fig. 5. X-ray diffractograms of Umm er Radhuma shales

Table 2. Chemical analysis of Umm er Radhuma shales

Sample No.	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>3</sub> O <sub>4</sub>	CaO	MgO	Na <sub>2</sub> O	KO	L.O.I.*	Total
1	45.27	10.33	3.64	0.60	9.46	1.26	0.55	28.11	99.22
2	49.54	11.03	4.62	0.96	9.13	0.87	0.57	23.68	100.40
3	43.45	9.64	4.16	1.08	10.21	1.96	0.50	29.65	100.65
4	58.24	13.10	4.58	6.00	1.98	0.30	0.80	15.64	100.64
5	44.58	9.97	3.65	2.08	9.83	1.12	0.60	27.48	99.31
6	49.99	11.20	4.13	1.26	5.74	traces	1.35	26.30	99.97
7	49.08	10.84	3.73	2.84	7.64	1.56	1.43	23.02	100.14
8	48.80	10.54	3.70	1.86	6.48	1.63	1.26	25.57	99.84

\* Loss of ignition

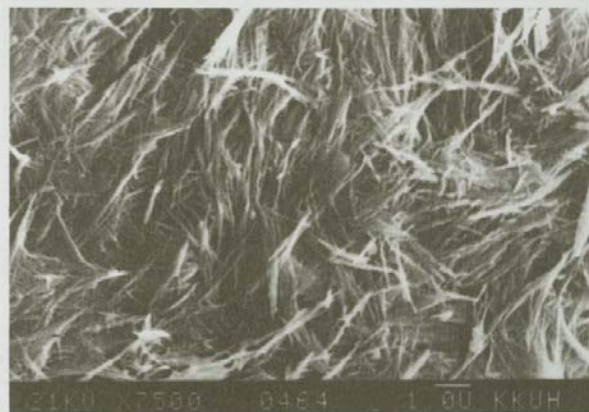
Table 2 shows the total chemical composition of the studied samples. The low percentage of CaO and the high specific surface area are the main reasons for the good rheologic behaviour. The presence of soluble salts in these shales was also obvious from the low electrical resistivity of their filtrate in filtration loss experiments (Table 3).

**Table 3. Rheological measurements in the presence of chlorides and hydroxides for Ummer Radhuma Shales**

Composition of suspension	$\rho$ ppg	$\mu_a$ (c.p)	$\mu_p$ (c.p.)	Y.P. lb/100 ft <sup>2</sup>	pH	R $\Omega$ .m.	GS lb/100 ft <sup>2</sup>	F.L. mL/7.5 mm	MCT in/32
8.67% clay + H <sub>2</sub> O	8.70	14.25	4.0	20.5	5.4	0.39	9/9.5	105	4.8
8.67 clay + 1% NaCl + H <sub>2</sub> O	8.70	26.75	6.5	40.5	5.6	0.24	20.5/31.3	9.6	4.6
8.70% clay + 1% CaCl <sub>2</sub> + H <sub>2</sub> O	8.70	17.25	4.5	25.5	5.2	0.30	12.5/12.5	104	4.9
8.70% clay + 1% NaOH + H <sub>2</sub> O	8.67	47.00	30.0	34.0	7.6	0.19	7/12	170	6.3
8.70% clay + 1% Ca(OH) <sub>2</sub> + H <sub>2</sub> O	8.73	7.50	7.0	1.0	7.6	0.36	2.5/8	150	5.6

The three forms of water in the structure of palygorskite were compared with the ideal amounts calculated on the basis of the structure of palygorskite  $\text{Si}_8(\text{Mg})_5\text{O}_{20}(\text{OH})_2(\text{OH}_2)_4 \cdot 4(\text{H}_2\text{O})$ . The results indicated that there are more structural hydroxyles in the studied samples than those proposed for the ideal structure calculated by Caillere and Henin [7].

The electron micrograph of the original clay sample clearly indicated the fibrous structure of the clay as shown in Fig. 6.

**Fig. 6. Electron micrograph of Ummer Radhuma palygorskite**

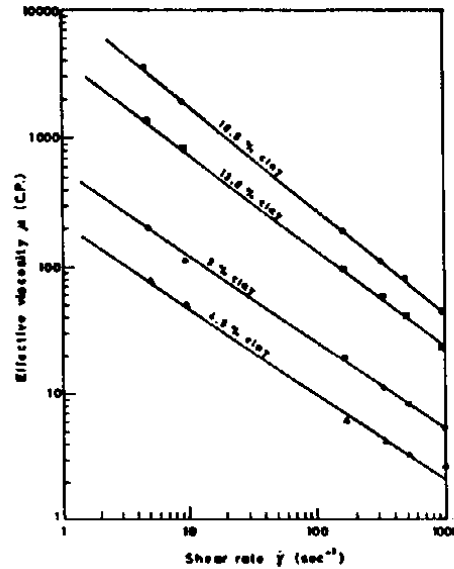


Fig. 7. Effective viscosity-shear rate relationship for different concentrations of Umm er Radhuma clay

The principal interest of measurements of apparent viscosity at various shear rates (Fig. 7) is to investigate the clay concentration, at which the suspension behaviour will be changed. The rheological behavior of Umm er Radhuma shales was similar to that of commercially used clays as shown in Fig. 8.

The concepts involving shear stress and shear rate and their measurement enable a mathematical description of the flow of drilling fluids. The shear rate/shear stress ratio of a non Newtonian fluid is not constant, which is true for most drilling fluids. Fig. 9 shows typical relations for the studied samples. These figures indicate the presence of relations which accurately describe flow characteristics of a drilling fluid over the shear rate ranges normally encountered in the drilling operations. Umm er Radhuma shales possess pseudoplastic behaviour. The log-log plot of various rheograms (Fig. 10) gives the following mathematical relation:

$$\tau = K \dot{\gamma}^n$$

where

$\tau$  shear stress (lb/100 ft<sup>2</sup>)

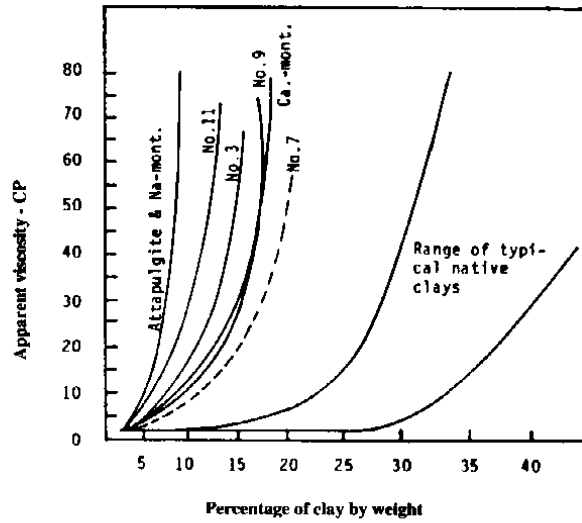


Fig. 8. Apparent viscosity vs. percentage of various types of clay in fresh water, including Umm er Radhuma clay samples.

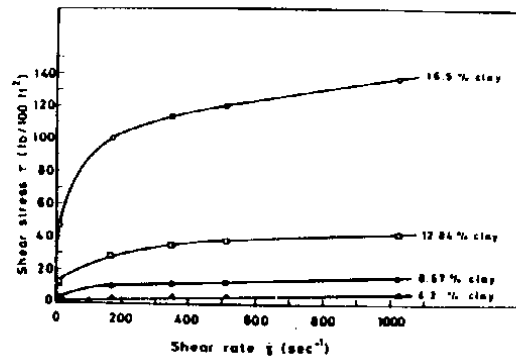


Fig. 9. Shear stress-shear rate relationships for different concentrations of Umm er Radhuma clay.

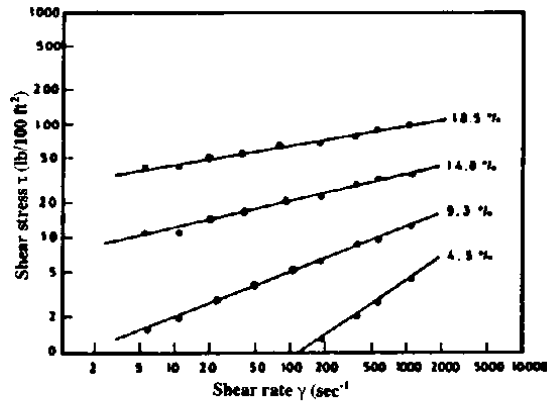


Fig. 10. Log-log plot of shear stress-shear rate relations for different clay concentrations of Umm er Radhuma clay

$\gamma$  shear rate (sec $^{-1}$ )

K consistency index (lb/100 ft $^2$ )

n measure of the degree of deviation of fluid from Newtonian behaviour

The limits which define the interpreted domains of fluid behaviour are primarily dependent upon morphology, granulometry, specific surface area and microporosity of clay minerals [10].

The effect of clay concentration on the rheologic properties particularly viscosity and yield point was studied (Figs 11 and 12). In general, viscosity depends on the concentrations of the solids put into the mud. The relation is given by the following equation:

$$\log \mu_a = - A + B \log C_p$$

which gives

$$\mu_a = A' C_p^B$$

where

$\mu_a$  apparent viscosity

$C_p$  clay weight %

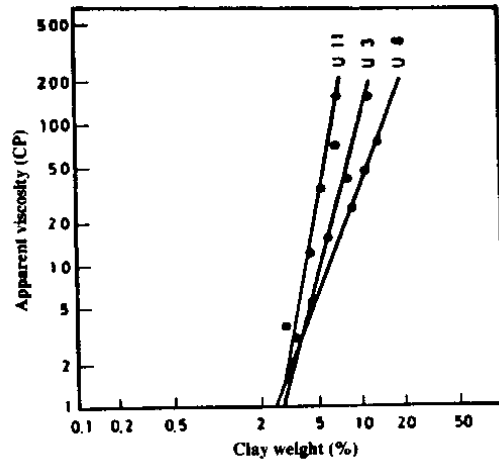


Fig. 11. Relationship between apparent viscosity and clay weight percent

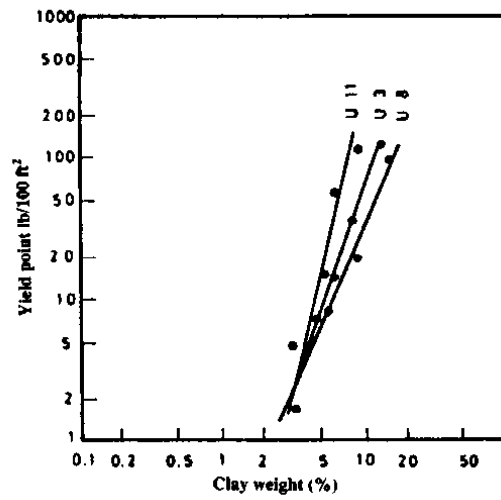


Fig. 12. Relationship between yield point and clay weight percent

A intercept with the ordinate

B slope of the line

A and B are functions of numerous parameters such as clay minerals content, measurement devices and operating conditions.

The yield point is also dependent on electro-chemical charges in the mud under flowing conditions. Particles of clay may be charged so that they attract each other and hence produce a high yield point or particles may repel one another and consequently give lower yield point.

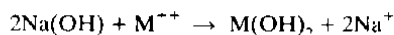
The same relations between yield point and clay concentration are described by the equation:

$$Y.P. = A C_p^B$$

where

Y.P. = yield point

The other measured properties are shown in Table 3. These properties include density, resistivity, pH, gel strength filtration loss and mud cake thickness, in the case of suspensions composed only of distilled water and clay, as well as by addition of various chlorides and hydroxides of sodium, calcium, magnesium and potassium. Among these chemicals, sodium hydroxide is distinguished by its positive effect on rheological properties. Umm er Radhuma suspensions showed good rheology in fresh water as well as in Sea water. Only filtration was higher in sea water suspensions. The addition of CMC controlled filtration loss as shown in Fig. 13. The optimum shear stress/shear rate relationship was obtained by mixing Umm er Radhuma clays with aquagel "bentonite" at a ratio of 7:3 as indicated by Fig. 14. The caustic soda is used to control pH and to improve the rheology of suspensions by precipitating of calcium and/or magnesium according to the following reaction:



where  $M^{++}$  denotes calcium or magnesium ions. The suppression or precipitation of these undesirable ions results in better physio-chemical properties of mud.

When 1% chloride ( $NaCl$ ,  $KCl$ ,  $CaCl_2$ , and  $MgCl_2$ ) was added to clay-water suspensions, the order of promoting effect of the cations on the rates of alteration of palygorskite seemed to be as follows:  $Mg^{++} > Ca^{++} > Na^+$  at 400°F. When hydroxides were added at the same concentration, the divalent cations ( $Mg^{++}$  and  $Ca^{++}$ ) showed a much higher promoting effect than monovalent cations ( $Na^+$  and  $K^+$ ) [8].

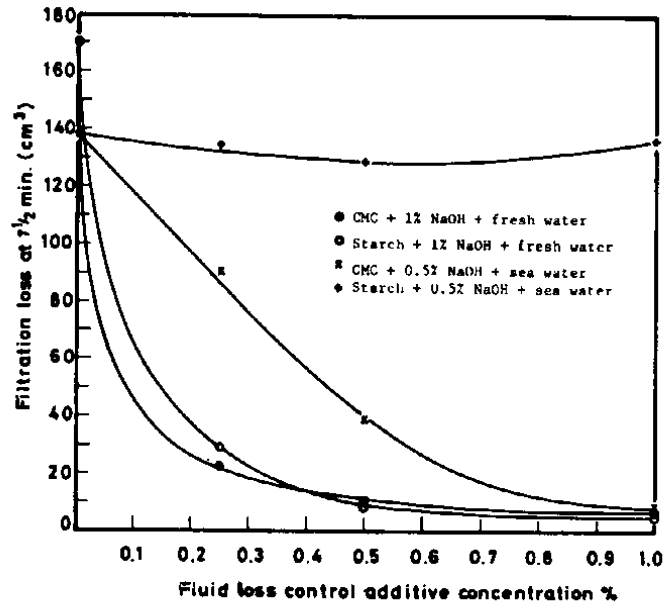


Fig. 13. Effect of chemical additives on filtration properties of Umm er Radhuma clay suspensions

### Conclusions

On the basis of our analysis, the following conclusions are given:

- 1) The mineralogical and chemical characterization proved the exclusive presence of palygorskite mineral in Umm er Radhuma formation. The non-clay minerals characterized in Umm er Radhuma (gypsum, dolomite and quartz) were of no sufficient importance. This suggests that, the clay could be commercially used as a basic constituent in drilling fluids.
- 2) The rheology of Umm er Radhuma shales indicated the presence of pseudo-plastic behaviour of suspensions very close to the commercially used clays. For all suspensions and beyond the Newtonian limits, it is observed that:
  - Decrease of the apparent viscosity as the shear rate increases,
  - Increase of viscosity and yield point with the increase of clay percent,

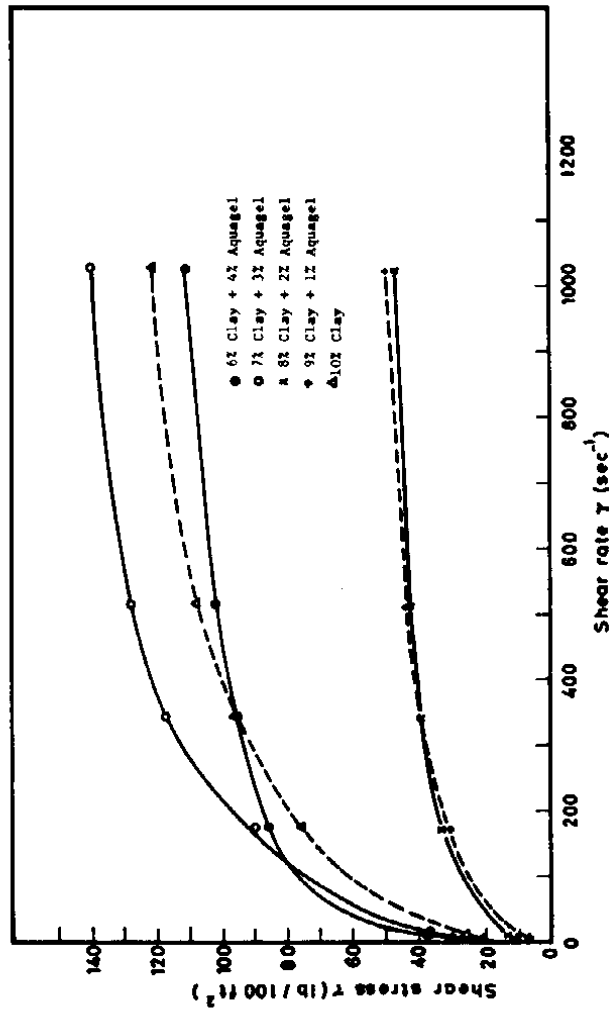


Fig. 14. Effect of aquagel addition on shear stress-shear rate relations of Unim or Radhuma clay suspensions

- Influence of chemical environment of suspensions on rheologic behaviour,
  - Improvement of rheology of activated clay by sodium hydroxide. Starch and CMC controlled filtration whereas bentonite "aquagel" improved viscosity.
- 3) The result of adding chlorides and hydroxides to palygorskite fluids was lowering of viscosities. However, in the presence of some electrolytes, poor Rheological behaviour was obtained due to the palygorskite alteration. From engineering point of view, these types of clays could be successfully used in oil-well drilling fluids, since they are comparable with industry standards.
  - 4) A serious commercial evaluation of Umm er Radhuma clays must be considered by the Saudi oil industry as all factors presented in this paper showed a positive prospective.

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## اختبار صخور الطفلة السعودية لاستخدامها في موائع الحفر

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(استلم في ٢٧/٢/١٩٩١م، قبل للنشر في ٣٠/٦/١٩٩١م)

ملخص البحث. يقدم هذا البحث نتائج التحاليل الكهروكيميائية وخواص الترشيح والسريان لمعلقات صخور طفلة أم الرضومة في المملكة العربية السعودية والتي أثبتت إمكانية استخدامها كمكوّن أساسي في موائع الحفر، كما أجريت دراسة مبدئية على الاحتياجات المستقبلية لمثل هذه الصخور في عمليات الحفر.

أظهرت التحاليل المعدنية والكيميائية لرواسب طفلة أم الرضومة وجود معدن الباليجورسكيت، كما أظهر التحليل الحبيبي لهذه الرواسب أن نسبة ٩٥٪ من حبيباتها تقع في مدى حبيبات المعادن الطينية أي أقل من ٢, ٠ ميكرومتر. تمت دراسة السلوك السرياني لمعلقات هذه الصخور قبل وبعد إضافة كلوريدات وهيدروكسيدات الصوديوم والبوتاسيوم والكالسيوم والماغنسيوم، كما تم ربط التغيرات في خواص السريان مع طبيعة المعادن الطينية في هذه الصخور.

ويعتقد أن المملكة العربية السعودية سوف تستثمر كميات هائلة من النقد لتزيد من حصتها في إنتاج الزيت لتفي بالطلب المتزايد على البترول في التسعينيات وسيكون لعمليات الحفر نصيب كبير من هذا الاستثمار، وفي تقديرنا فإن استخدام صخور طفلة أم الرضومة في حفر آبار البترول والمياه في المملكة العربية السعودية سوف توفر ملايين الدولارات التي قد تنفق لتأمين المواد الخام اللازمة لموائع الحفر من خارج المملكة.