Investigation the Effect of Some Drilling Fluid Properties on Rock Drilling Rate

Mohamed A. Y[1]; Mohamed A. Sayed[2]; Gamal Y. Boghdady[3]; Mahrous A. M. Ali[4]; Ahmed S. Mohamed[5]*

Abstract—This work presents an extensive experimental study to investigate the effect of drilling fluid properties on rate of penetration (ROP). Fresh water and water based mud were selected to study the effects of mud properties on ROP. Drilling Fluid was used to drill samples of Aswan sandstone (Akaba quarry in Aswan), Isawya limestone (Sohag), limestone (Assiut cement quarry), and Minya marble (El sheikh Fadel quarry in Minya) Egypt. These formations were tested to study the effects of drilling fluid properties on ROP. The drilling fluid properties studied were mud weight (barite -A weighting agent), mud viscosity, (bentonite -A viscosity agent), and pH (Caustic soda - pH Concentration) which are giving rheological properties of the drilling fluid. Mud weights(MW) used are 8.3, 9.2, 10, 10.8, 11.6, and12.4 (pound per gallon) ppg, whereas mud viscosities are 26, 30, 35, 40, 45, and 50(second per quart) sec⁄qrt, and pH values are 7, 9, 10, 11, 12, and 13. The results are used to determine suitable mud weight (MW), mud viscosity, and pH that give a suitable ROP. The results of the laboratory carried out for drilling, limestone, Aswan sandstone, and Minya marble the best mud weight that gives the maximum value of ROP is 10.8 ppg, whereas 10 ppg. was the suitable MW that gives the best value of penetration rate for drilling Isawya limestone. From the results, it is found that the optimum viscosity, MW, and pH are, 40 s⁄qrt., 10.8 ppg., and 10 for drilling in Assiut limestone, and Aswan sandstone, and 35 s⁄qrt, 10.8 ppg, and 9 pH for drilling in Isawya limestone, and 40 s⁄qrt., 10.8 ppg., and 10 (pH) for drilling Minya Marble.

keywords: Rate of penetration, Mud Properties, Drilling fluid, Viscosity, Mud weight, pH

1 INTRODUCTION

Drilling process is very an important for all operations in mining technology (surface and underground). High ROP is an index for drilling operation success, this operation depended on controllable and uncontrollable factors to find the good relationship between all of these parameters and the drillablity index. One of these controllable factors is fluid properties so this paper will focus on some mud properties such as MW, viscosity, and pH which affect directly on the drillablity [1]. During drilling activities, drilling mud is usually utilized to, extend bit life, control well pressure, and reduce fluid loss and many more. It's very essential to identify the parameters that affect the ROP and the efficiency of the drilling, such as the type and properties of the drilling fluid. Drilling fluid properties tend to have great influence on the level in which ROP would have ordinarily been accomplished [2-3]. It has long been known that the drilling fluid density affects the ROP. This early fact of etiquette has been established and confirmed by many laboratory studies Fast ROP is the aim in each drilling activity and if achieved can reduce the well drilling cost. Thus, the selection of mud properties is a challenge one faces throughout drilling operations. In revealed that the ROP increased by decreasing mud properties [4]..

Data collected from Field and analyzed it to identify the properties of a drilling fluid that improve the ROP and to evaluate the impact of particular fluid properties on ROP throughout tests [5]. These tests are utilized to estimate the economics of a drilling fluid treatment program to deliver optimal drilling performance and minimum cost drilling instead of reducing the cost of drilling fluids. They concluded that there is an inverse relationship between the ROP and drilling mud properties .

Machine of diamond drilling was used to get cores of Aswan sandstone and Minya marble, and two types of limestone formation of different properties (five cores for each rock). The outside and inside diameter of the bit used is 50 and 42 mm respectively. All the drilling series were executed at RPM 1200. Therefore, the drilling bit has a series of drilling data for the rocks, in a certain RPM and the load applied to the bit as shown in Figure (1) .

The aim of this work is to examine the influence of mud properties on ROP and Specific energy (SE) at constant WOB, and Rotary Speed (RPM) in different tested rocks.

2 GEOLOGY OF THE TESTED ROCKS

The four-rock sample collected from different governorate (Minya, Assiut, Sohag, and Aswan), Egypt. The Assiut region of middle Egypt may as a preliminary approximation can be regarded as representative of the general structural style of the (stable) paleogeographic and structural domain of the Arabian Nubian shelf, bounded to the northwest by the mobile zone of the unstable shelf. It comprises the plateau which forms the mesa west and east of the Nile mesa (the western and eastern deserts). Wadi el Assiuty Eocene plateau bounding the Nile valley near Assiut is composed of limestone (Drunka formation) which is quarried for cement industry.

Isawya limestone consist of the different rock types in the area east of Sohag, between latitude (26° 33' 57" N.) north, and longitude (31° 49' 14 ") East, covering about 400 km².

The area under investigation was covered by limestone, sand, silt, clays, conglomerate and red limestone breccias. Geomorphological the area extends between Sohag and Naga Hamadi was investigated and classified in relation to the drainage pattern and drainage types, where the main Wadis in the area were determined. Carbonate rock are mineralogical composed mainly of calcite (CaCO3) with variable amounts of accessory minerals. A similar proportion is composed predominately of dolomite (CaMg(CO3)2) which alters considerably the geotechnical properties .

Aswan sandstone, the Nubian sandstone was extracted from the available geological maps of southern Egypt. Nubian Sandstone over a kilometer in the Nubian strata were deposited in south western Egypt controlled primarily by marine transgressions and regressions with alluvial plain sand with interbedded channel and soil zone deposits interleaved with marine clay and silt. This cycle constitute the typical Nubian sandstone and represent continuously changing environments from fluvial and deltaic deposition.

Minya marble samples of the study are collected from El sheikh Fadel marble quarry. Co-ordinate Minya marble Latitude (28° 20' 49.44" N), Longitude (31° 48' 18.99" E) and elevation 43 m. Minya Marble is a crystalline, compact variety of metamorphosed limestone, consisting primarily of calcite (CaCO3), dolomite (CaMg(CO3)2) or a combination of both minerals. Pure calcite is white, but mineral impurities add color in variegated patterns. In terms of geological definition, it is a metamorphosed limestone produced by recrystallization under condition of thermal and also regional metamorphism. In commercial parlance almost, any rocks consisting of calcium and/or magnesium carbonate which can take polish easily more especially un metamorphosed limestone are termed as Minya marble. An experimental works was executed on, sandstone, limestone, and marble samples from the different four locations are located in Figure (2).

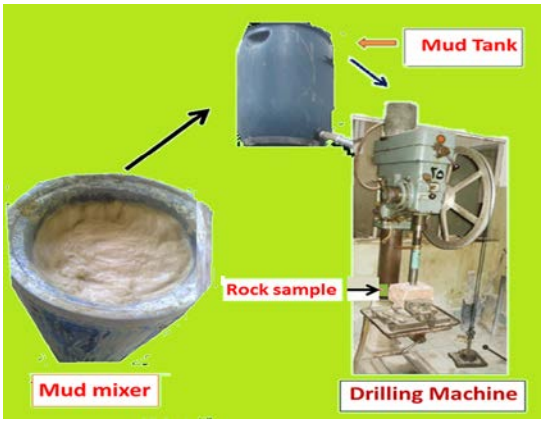

Fig. 1: Diamond drilling machine

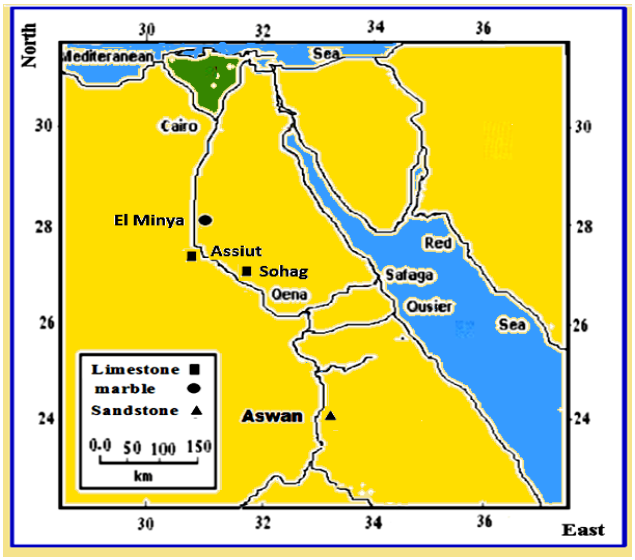

Fig. 2: The four locations for studied rocks.

3 METHODOLOGY

In this work a series of the experiments were conducted under constant WOB (the optimum WOB of tested rocks), and uniform rotary speed (1200 RPM). The additives materials Barite, bentonite, and caustic soda used in drilling fluid were obtained from Sphinx Company; in Alexandria, Egypt. Barite was used to adjust the density, bentonite to adjust the viscosity and (NaOH) to adjust the pH of mud samples [6-8]. Two mud samples were used in this test; the first mud sample contains two additives (bentonite and NaOH), whereas the second sample contains three additives (barite, bentonite and Sodium hydroxide). The equipment used for this experimental work include, mud balance used for calculating mud weight, March funnel was used to determine viscosity of the mud samples, mixer was utilized for preparing mud samples with capacity of 30 Liter, Tank to pump mud in the drilling machine under head pressure, and sensitive Balance.

Blocks are formed by diamond saw from every rock type for the drilling test. Diamond core bit is used for these tests using the diamond drilling machine. Suspension of mud samples was prepared by immersing the bentonit, barite, and NaOH in 30 Liter fresh water and stirred vigorously into the mixer for 4 hours to achieve homogeneity, and then set them in the tank to pump into drilling machine.

The drilling data and rock experiments were registered. Drilling fluid properties, optimum WOB, length of borehole, high speed, and drilling time are recorded as results of drilling process. These results used to estimate the average ROP at a specific drilling fluid. Four trials were carried out for fluid drilling properties. choice of the drilling fluid properties range for the bit were made by applying minimum drilling fluid properties where the bit was just capable of drilling the rock and maximum drilling fluid properties just below the point where the drill commenced to showed or stall (distressed) drilling. Three drilling fluid properties increments for each rock were selected between these limits. All drilling trials were executed at 1200 RPM motor speed [8-10].

[1]*Prof. at the Mining & Petroleum Dept., Faculty of Engineering Cairo, Al-Azhar University*
[2,3] *Prof. at the Mining and Metallurgical Dept. Faculty of Engineering, Assiut University*
[4]*Assist Prof. at the Mining & Petroleum Dept., Faculty of Engineering Qena, Al-Azhar University*
[5]*Teaching Asst., at the Mining & Petroleum Dept., Faculty of Engineering Qena, Al-Azhar University cor.: ahmedsayed8686@yahoo.com*

4 RESULTS AND DISCUSSION

The drilling fluid properties that will be discussed are mud weight, viscosity, and pH. The results obtained from the laboratory samples, which using varying mud density, viscosity, and pH to check the effects of mud properties on ROP and SE.

4.1 Effect of Mud Weight (MW) on the ROP

Table (1) gives final calculation of rate of penetration and specific energy for different rock type under conditions (pH) = 9 and viscosity 40, RPM 1200), as regard the optimum WOB according to rock type. The relationship between ROP and MW was illustrated in Figure (3).

Table 1. Final result of ROP and SE according to variable MW

MW, ppg.	Aswan sandstone, WOB = 60 kg		Isawya limestone WOB = 96 kg		Assuit limestone WOB = 84 kg		Minya marble WOB = 120 kg	
	ROP, cm/min	SE, MPa	ROP, cm/min	SE, MPa	ROP, cm/min	SE, MPa	ROP, cm/min	SE, MPa
8.3	40.57	222.92	48.00	313.91	51.13	135.74	16.10	1271.7
9.2	10.78	839.16	12.33	1222.04	6.73	1031.35	4.40	4653.06
10	10.150	891.41	13.80	1091.87	6.17	1125.65	2.09	9795.91
10.8	11.32	799.56	10.43	1444.66	7.00	991.58	2.79	7338.16
11.6	6.090	1485.69	6.17	2442.1	3.56	1953.03	2.12	9657.30
12.4	4.179	2165.07	4.34	3471.83	2.94	2359.16	1.76	11632.65

From table (1) and Figure (3) it is clear that, an increase of the mud weight (MW) produces a decrease in (ROP). From Figure (3) for Isawya limestone, the best mud weight (MW) =10 ppg that gives maximum value of ROP =13.8 cm/min., whereas for Aswan sandstone, Assiut limestone, and Minya marble, the best mud weight (MW) was 10.8 ppg, which gives maximum value of ROP (11.32 cm/min, 7.0 cm /min and 2.79 cm/min) respectively. At mud weight (MW) = 10.8 ppg, and 1200 rpm, ROP in Aswan sandstone is about (1.61, 1.09, and 4.06) times more than of Assiut limestone, Isawya limestone, and Minya marble respectively

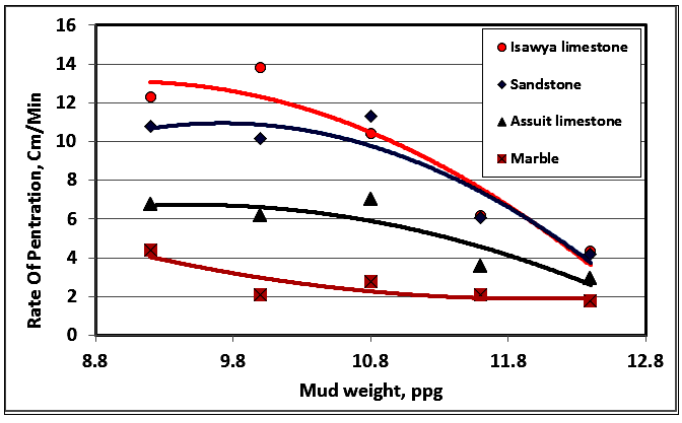

Fig.3: Relation between mud weight and ROP for four tested rocks

4.2 Effect of Viscosity on ROP and SE in tested rocks

The experimental data for drilling the four types of rocks and the method of calculation were presented in table (2). A mud sample has a constant pH = 9 and density 8.33 ppg.

Table 2. Final result of ROP and SE according to variable viscosity

Viscosity, sec/qrt.	Aswan sandstone WOB = 60 kg		Isawya Limestone WOB = 96 kg		Assuit Limestone WOB = 84 kg		Minya marble WOB = 120 kg	
	ROP, cm/min	SE, MPa	ROP, cm/min	SE, MPa	ROP, cm/min	SE, MPa	ROP, cm/min	SE, MPa
26	40.57	222.92	48.00	313.91	51.13	135.74	16.10	1271.7
30	17.89	505.69	18.00	837.10	24.83	279.64	7.04	2907.75
35	12.29	735.96	16.62	906.6	18.41	377.05	5.03	4070.27
40	14.52	623.13	12.44	1211.23	25.78	269.32	6.13	3338.79
45	9.94	910.61	4.46	3378.42	15.39	451.14	3.95	5177.91
50	4.61	1963.51	4.59	3282.74	10.38	668.88	3.58	5715.65

Relationships between viscosity and ROP and are shown in Figure (4) according to data in table (2), From Figure (4) It was found that ROP varied related to the variation in mud viscosity when the other fluid properties such as pH = 9 and density 8.33 ppg. are constant. ROP reduced from 25 cm/min to 3.5 cm/min within the fluid viscosity change for tested rocks. From Figure (4) for Isawya limestone, the best viscosity is 35 Sec/qrt that gives maximum value of rate of penetration (ROP=16.62 cm/min.), for Aswan sandstone, Assiut limestone, and Minya marble, the best viscosity is 40 sec/qrt and that give maximum value of rate of penetration (14.52 cm/min, 25.782 cm/ min and 6.132 cm/min) respectively. At viscosity 40 sec/qrt, the ROP in Assiut limestone is about (1.78, 2.1, and 4.2) times more than of Aswan sandstone, Isawya limestone, and Minya marble respectively.

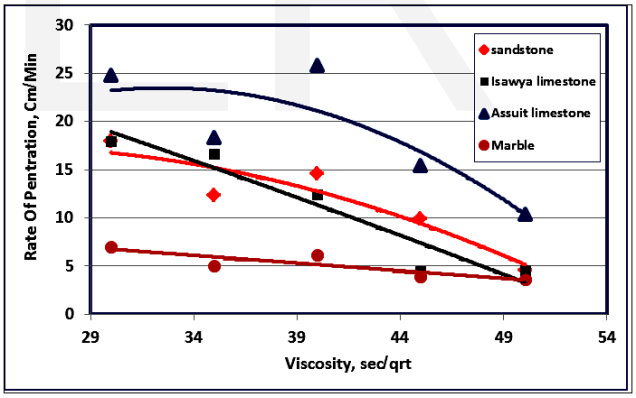

Fig. 4: Relation between viscosity and ROP for four tested rocks

4.3 Effect of pH on ROP and SE in four tested rocks

The experimental data for drilling the four types of rocks and the method of calculation were presented in table (3).
Effect of pH on the ROP is given in Figure (5). It is clear that, an increase in the pH produces a decrease in the OP in drilling all tested rock. From Figure (5) for Aswan sandstone, and Assiut limestone the best pH is 10 that gives maximum value of ROP = 14.52, and 25.782 cm/min respectively, whereas for Isawya limestone, and Minya marble the best pH is 9 that give maximum value of ROP 12.49 and 6.32 cm/min respectively. At pH = 9, and 1200 rpm, ROP in Assiut limestone is about (2, 1.9, 3.8) times more than of Aswan sandstone, and Isawya limestone, and Minya marble respectively.

Table 3: Final result of ROP and SE according to variable pH.

pH	Aswan Sandston WOB = 60 kg		Isawya Limestone WOB = 96 kg		Assuit Limestone WOB = 84 kg		Minya marble WOB = 120 kg	
	ROP, cm/Min	SE, MPa	ROP, Cm/Min	SE, MPa	ROP, cm/Min	SE, MPa	ROP, Cm/Min	SE, MPa
7	40.57	222.92	48.00	313.91	51.13	135.74	16.10	1271.70
9	11.874	761.99	12.486	1206.78	23.748	292.36	6.318	3240.50
10	14.520	623.13	12.438	1211.43	25.782	269.297	6.132	3338.79
11	11.064	817.77	11.382	1323.82	15.63	444.211	6.061	3377.90
12	7.242	1249.36	10.816	1393.10	9.069	765.58	6.026	3397.50
13	6.900	1311.28	9.715	1550.98	8.876	782.22	5.975	3426.52

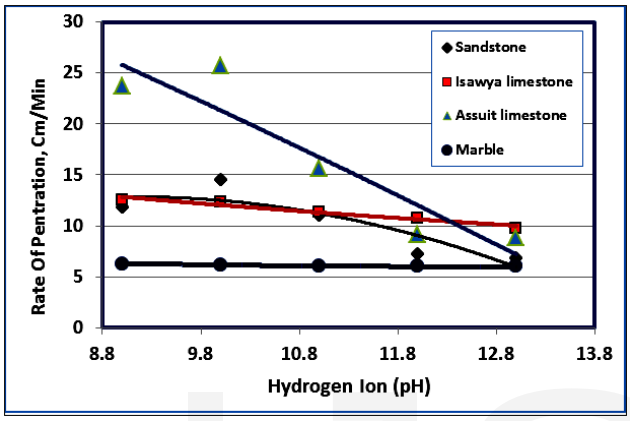

Fig. 5: Relation between pH and ROP for four tested rocks

4.4 Relationship between MW, Viscosity, pH, and SE

Figures (6 to 8) show that at high Mud Weight, viscosity, and pH, the SE increases for the four rock types, whereas decreasing Mud Weight, Viscosity, and pH, are associated by decreasing in SE. From the results and Figures (6 to 8) it can be seen that drilling fluid properties Mud Weight= 10.8 ppg, viscosity = 40 sec/qrt., and pH=10 are suitable for drilling sandstone, and Assiut limestone, whereas Mud Weight = 10.8 ppg, viscosity = 40 sec/qrt., pH = 9 are suitable for drilling in Aswan sandstone, Assiut limestone, and Minya marble, and Mud Weight = 10.8, viscosity = 35 sec/qrt. pH = 9 are proper for drilling in Isawya Limestone.

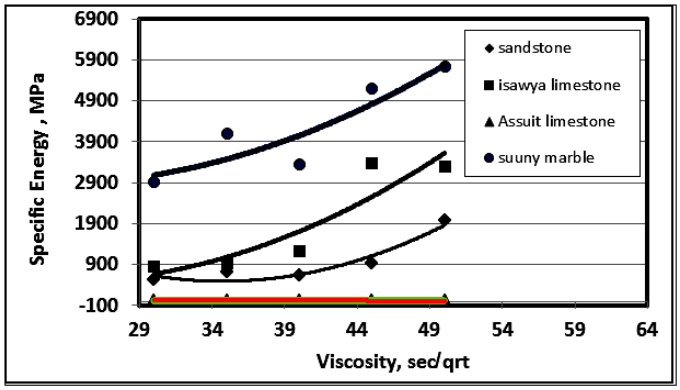

Fig. 6: Relation between Viscosity and SE for four tested rocks

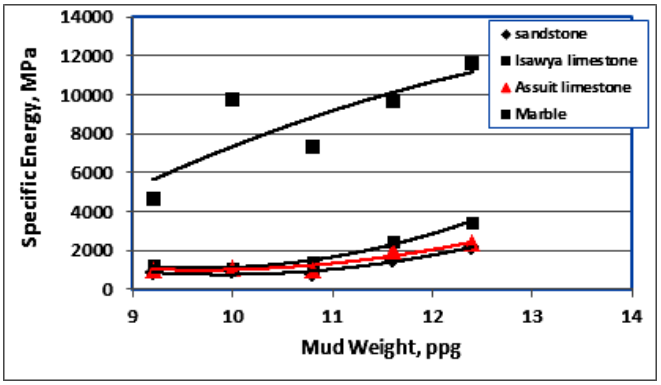

Fig. 7: Relation between MW and SE for four tested rocks

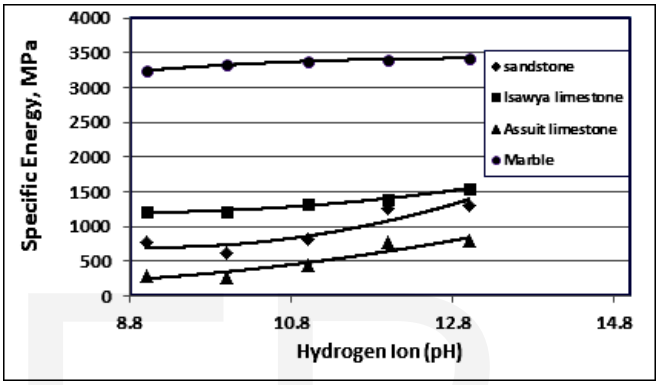

Fig. 8: Relation between pH and SE for four tested rocks

5 CONCLUSIONS

From The results of the laboratory tests were carried out on the selected rocks we can conclude that :

1. For drilling , Assiut limestone, Aswan sandstone, and marble the optimum mud weight that gives the maximum value of ROP is 10.8 ppg, whereas 10 ppg. was the optimum mud weight that gives the best value of penetration rate for drilling Isawya limestone.

2. From the results, it is found that the optimum viscosity, mud weight, and pH are, 40 s/qrt., 10.8 ppg., and 10 for drilling in Assiut limestone, and sandstone, and 35 s/qrt, 10.8 ppg, and 9 pH for drilling in Isawya limestone, and 40 s/qrt., 10.8 ppg., and 10 (pH) for drilling Marble.

3. The lower SE for drilling in Isawya limestone was achieved at viscosity= 35 s/qrt, mud weight = 10 ppg, and pH = 9, and it is achieved at viscosity = 40 s/qrt, mud weight = 10.8 ppg,, and pH = 10, for both Assiut limestone and sandstone, whereas it is achieved at viscosity = 40 s/qrt, mud weight = 10.8 ppg, and pH = 9 for marble.

4. When using the drilling with water, the drilling operations is four times greater than mud, but is not effective to keep hydrostatic pressure to keep stability in hole and eliminate the ground gases.

5. The best drilling conditions for all tested rocks are given in Table 4.

Table 4: The suitable drilling fluid conditions for all tested rock at constant RPM (1200)

Rock	MW, (ppg)	Viscosity (sec/qrt)	PH	WOB, (Kg)	ROP, (cm/min)	SE, (MPa)
Aswan sandstone	10.8	40	10	60	11.32	799.56
Isawya Limestone	10	35	9	96	13.8	1091.87
Assuit Limestone	10.8	40	10	84	7.00	991.58
Minya marble	10.8	40	9	120	2.79	7338.16

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