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SOME DRILLING PARAMETERS AS A TOOL TO PREDICT DIFFERENT CATEGORIES OF ROCKS

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Experimental works have been performed on five types of limestone, two types of marble and two types of granite representing sedimentary, metamorphic and igneous rocks respectively. Rate of penetration (ROP) of diamond core drill with different thrust load and rotary speeds have been obtained. Drilling Specific energy (SE) has been determined in all types of rocks under investigation at different applied loads and rotary speeds. The results were obtained for rate of penetration (ROP) to show the variation in specific energy with the different rocks. A new dimensionless index UCS/SE (Uniaxial Compressive Strength divided by specific energy) was calculated and the rates of penetration against UCS/SE for all rocks were plotted. The interpretation of these relationships clears that at lower thrust loads and higher rotary speeds the three groups of rocks were classified distinctly as three categories. Whereas, at higher thrust loads and higher rotary speeds were clearly classified as two categories, one for sedimentary only and the other for metamorphic and igneous together. From these results with other information obtained by analysis of drill cuttings and the results that have been obtained from relationships, it can be possible to identify the rock type being drilled.

KEYWORDS: *drilling specific energy, new dimensionless index (UCS/SE)*

INTRODUCTION

Drilling is an essential and integral process of mineral exploration to present a clear picture of extent of any ore body, its mineral content, the stratigraphy or to confirm any geological or indirect geological interpretations of what is lying below the earth's surface. The type of strata and structure to be drilled has a significant influence on the drilling performance of a bit. Resistance to penetration, resistance to shearing action of the bit in rotation and the degree of abrasiveness are the properties that would be expected to have the greatest influence. However, it is important to note that the prediction of physical and mechanical properties of rock formations from rates of penetration may help the mining engineer to control the changing characteristics of the formations [1, 2, 3].

A range of performance indicators reflects transition of the drill bit from one strata type into another. Changes in the rate of penetration or torque give an immediate indication of a "drilling break", but the specific energy gives a better indication of the nature of the formation being drilled and its strength. Specific energy may be used in combination with other drilling variables and drill-chip examination to enhance strata information [4, 5].

In the field, however, the most holes are drilled into areas of unknown geology or regions for which knowledge is limited. Measurements of specific energy can be used to indicate the location of strata boundaries and voids, etc [6]. Specific energy (SE) is the simplest factor for specifying the mechanical performance of a machine and Uniaxial Compressive Strength (UCS) is the simplest factor for specifying the rock.

The comparative efficiency of the drilling operation can be expressed by the dimensionless ratio (UCS/SE) [7].

Establishing a mean of identifying the actual rock type being drilled is still in its early stages. However, research at Nottingham University has produced some very encouraging results.Several samples consisting on limestones and sandstones were cored and the drill parameters monitored. The penetration rate is plotted against the Uniaxial compressive strength divided by specific energy (UCS/SE). The results show that the two lithologies group fall into distinct areas of the plot [6, 8].

The current research is being extended to other rock types, sedimentary, metamorphic and igneous rocks to see if they too fall into distinct zones. The aim of this study is to provide drilling personnel with a means of identifying the actual rock to be drilled using diamond core drilling parameters. To do this, it is required to investigate the variation of drilling specific energy with the three rock categories. The method uses a term referred to as dimensionless index, UCS/SE, where UCS is the Uniaxial Compressive Strength and SE is Specific Energy.

DEFINITION OF SPECIFIC ENERGY

Teale defines specific energy as "the energy required to excavate a unit volume of rock". The specific energy of drilling may be defined as the quantity of energy from a source expended through the bit to drill volume of rock. It is a variable of the drilling process that is dependent on all the main drilling parameters: weight on bit, rotational speed, penetration rate and strength of rock. For example, the specific energy in a soft formation will differ from that in a hard one. Teale also developed an equation to calculate the specific energy from drilling. He considered it as a useful rock quality index [9].

$$\text{Specific energy (SE)} = \frac{F}{A} + \frac{2\Pi NT}{AU} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where, F is thrust, N is rotating speed, A is cross-sectional area of the hole, U is penetration rate and T is the torque. Specific energy can be used for assessment of drilling performance- that is, the combination of bit and drilling parameters that gives the lowest specific energy may be considered as optimum [5, 10].

In this original paper, Teale indicated that the minimum value of specific energy in terms of volume corresponded to uniaxial compressive strength of rock in the equation, irrespective of drilling process. However, Moller [11] has shown that specific energy is related to the uniaxial compressive strength (C_0) according to the relation:

$$SE_V = C_0 x10\text{-}3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

It follows that the value of SEV as determined by equation (2) is too small in comparison with Teale's minimum specific energy.

The specific energy of rock when drilled by a rotary drill is determined from the following equation [11, 12].

$$SEv = \frac{2.35 WN}{dR_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where,

W = weight on bit, (kg)

N = revolution per min.

d = diameter of bit (mm)

P_R = penetration rate (m/hr), and

SEv =specific energy, MJ/m^3 or J/cm^3.

Note that the quantity SE_v has the same dimensions as the stress and that a convenient unit for specific energy is the MPa (an equivalent unit for specific energy is the J/cm^3 which is numerically identical to the MPa) [13]. According to the condition of applications, equation (1) can be put into the following form:

$$SE = 628.30 \frac{NT}{AROP} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where,

A is cross-sectional area, mm^2

N is revolution per min.

T is torque, N.m, and

ROP is rate of penetration, cm/min.

TESTED ROCKS

Block samples from metamorphic, igneous and sedimentary rocks were chosen. Two types of marbles namely white and black marble represent metamorphic rocks from Wadi El- Miah, Eastern Desert Egypt. Two types of granite namely pink and black granite from Aswan, Egypt, represent igneous rocks. Five samples of limestones, three from Assiut namely Zaraby, Mankabad, and Assiut Cement Company quarry. And one from Issawyia, East Sohag, and the last rock unit from Beni Khalid quarry, Samalout, Mania. The geo-technical properties of rocks, which are carried out in this study, involve physical and mechanical properties as well as drilling rates. Drillability has been studied using core-drilling technique and the penetration rate is expressed in cm/min. Drilling tests conducted using different applied loads: 15, 30, 45, 60, 75 and 90 kg for all limestone rock units, and 30, 45, 60, 75 and 90 kg for marbles, and 90, 120, 150, 180 and 210 kg for granites. The rotating speeds, which have been tested under different loads, are 300 and 1000 rpm. Then, rate of penetration (ROP) is measured and calculated for different conditions of applying load and speed. Cubes measuring 20X15X 10 cm sizes are formed by diamond saw from each type of rock for the drilling tests. Diamond core drilling is applied for the tests. The effects of operational parameters of drilling on the rate of penetration have been studied [14].

The present study will concentrate on calculating the specific energies consumed during drilling tests for all tested rocks and comparing these energies for each rock type. Thereafter, a new index UCS/SE is calculated for all tested rocks at different loads and rotary speeds. Relationships between the rate of penetration and specific energy for all rocks are determined to give a comparison between the consumption of energy in the three types of rock being drilled. Relationships between UCS/SE and the rate of penetration (ROP) are also determined for sedimentary (limestones), metamorphic (marbles) and igneous rocks (granites) to see if they fall into distinct zones.

CALCULATION OF (SE) AND (UCS/SE)

Specific energy (SE) is calculated for all types of rocks by using equation (4). The dimensionless index UCS/SE is also determined for all types of rocks at different applied loads and actual rotary speeds using the calculated specific energy and the uniaxial compressive strength of tested rocks. Tables 1, 2 and 3 give an example for the calculation of specific energy (SE) and UCS/SE in limestones, marbles and granites at different loads and drilling speed of 1000 rpm. Each rock type has been represented by its compressive strength. By the same way results of specific energy and UCS/SE for all rocks at different loads and drilling speed of 300 rpm could be obtained from tables 4, 5 and 6.

RESULTS AND DISCUSSIONS

I. Variation of Specific Energy with the Rock Types

Values of drilling rate and specific energy for limestones, marbles and granites tables have been averaged and one value for each applied rotary speed represents each rock group. Each average value of drilling rate and specific energy was determined as an arithmetic mean for the values of each rock group related to nominal speed. Tables 4 and 5 illustrate the specific energy and UCS/SE for limestones, marbles and granites at 1000 and 300 rpm and different loads for new bit respectively. Then curve fitting was made for the average values of drilling rate to obtain empirical equations to represent the relationship between specific energy (SE) and Rate of penetration (ROP) in the different rocks [15, 16]. Both experimental and fitting values of rate of penetration (ROP) were plotted against the specific energy (SE) for all rocks at applied different loads on bit (WOB) as shown in figures 1 and 2. The most suitable mathematical equations to fit the data were given and written , related to each curve in the figures. Figures (1, 2) show that the specific energy for all tested rocks at 1000 and 300 rpm and under different loads on new bit decreases with increasing drilling rate. As the thrust load increases, the work lost in friction will constitute a rapid decrease in the total work done. This effect will contribute to fall in specific energy. However, this fall will not continue indefinitely, a stage may be reached when the tool is pushed so heavily into the rock that it becomes overloaded and clogs.

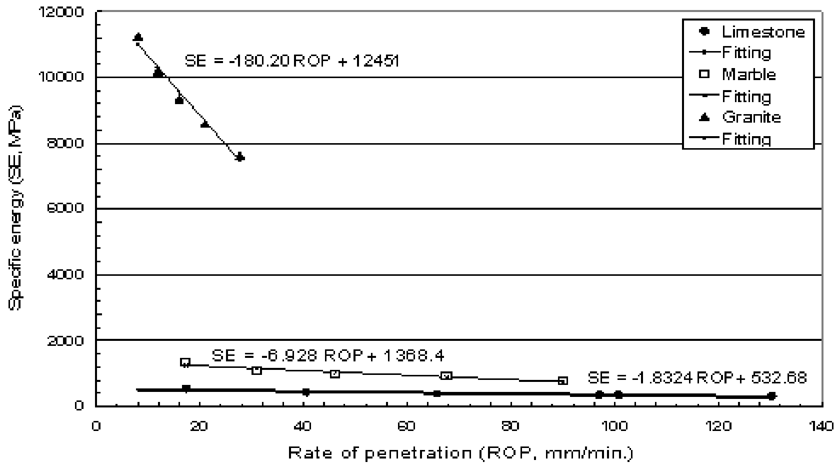

Figure (1) Relationship between average rate of penetration and specific energy for all rocks at different loads and drilling speed of 1000 rpm

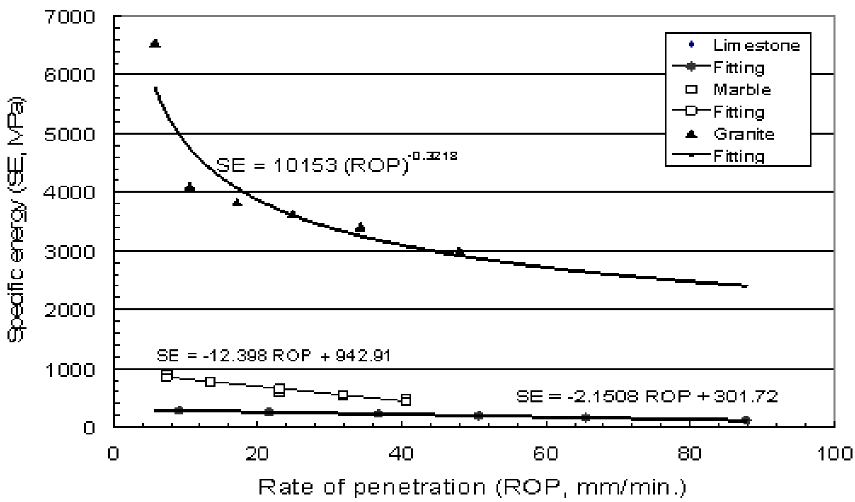

Figure (2) Relationship between average rate of penetration and specific energy for all rocks at different loads and drilling speed of 300 rpm

The figures show that generally, the specific energy for all rocks decreased with the increase in the drilling rate. Comparing the plotted data on figures 1 and 2, it can be seen that as the drilling rate was increased, the magnitude of the change in specific energy was not the same for limestone, marble and granite. Then, the igneous rock types have lower drilling rates and higher specific energy than the metamorphic and sedimentary rock types under investigation.

Tables (1, 2, and 3) give the values of specific energy and (UCS/SE) for limestones, marbles, and granites at 300, and 1000 rpm and different loads respectively. Also tables (4 and 5) give the average values of rate of penetration and specific energy at rotary speed 1000 and 300 rpm at different loads (WOB) respectively for different rock categories.

Table1: Specific energy and UCS/SE for limestones at 300, and 1000 rpm and different loads.

WOB, Kg	UCS, MPa	T, N.m	SE, Mpa		(UCS/SE)*10^{-3}		ROP, mm/min.	
			300 rpm	1000 rpm	300 Rpm	1000 rpm	300 rpm	1000 rpm
15	6.34	2.2	124.2	216.4	51.05	29.3	21	40.2
	9.19	1.4	218.32	335.2	42.09	27.42	7.6	16.5
	12.23	1.6	296.3	585.28	41.28	20.90	6.4	10.8
	16.02	1.6	326.95	645	49	24.84	5.8	9.8
	27.05	2.1	529.5	892	51.09	30.33	4.7	9.3
30	6.34	4.3	116.9	203.2	54.23	31.2	43.6	86.3
	9.19	2.8	155.07	250.3	59.26	36.7	21.4	44.2
	12.23	3.2	197.5	499.7	61.92	24.47	19.2	25.3
	16.02	3.1	258.7	516.7	61.93	31	14.2	23.7
	27.05	4.1	495.8	704.2	54.56	38.41	9.8	23
45	6.34	6.5	109.3	194.9	58.01	32.52	70.5	131.8
	9.19	4.2	126.98	242.2	72.37	37.94	39.2	68.5
	12.23	4.8	175.6	444.1	69.65	27.54	32.4	42.7
	16.02	4.7	221	372.8	72.49	42.97	25.2	49.8
	27.05	6.2	440	684.2	61.48	39.54	16.7	35.8
60	6.34	8.6	103.7	174	61.14	36.44	98.3	195.3
	9.19	5.6	108.63	232.1	84.6	39.6	61.1	95.3
	12.23	6.4	175.6	413.1	69.65	29.61	32.4	61.2
	16.02	6.2	202.4	299.1	72.49	53.56	36.3	81.9
	27.05	8.3	390.3	635.4	61.48	42.57	25.2	51.6
75	9.19	10.8	103.25	207.1	89.01	44.37	79.2	131.6
	12.23	6.9	135.4	359.1	90.32	34.06	70	88
	16.02	8	95.4	284.5	81.99	56.31	47.3	108.3
	27.05	7.8	365.7	544.9	73.97	49.64	33.7	75.4

90	9.19	8.3	96.35	200.9	95.38	45.74	102.1	163.2
	12.23	9.5	118.1	333.6	103.56	36.66	95.3	112.5
	16.02	9.3	167	275.8	95.93	58.09	66	133.2
	27.05	12.4	348.2	435	77.69	62.18	42.2	112.6

Table 2: Specific energy and UCS/SE for Marbles at 300, and 1000 rpm and different loads

WOB, Kg	UCS, MPa	T, N.m	SE, MPa		$(UCS/SE)*10^{-3}$		ROP, mm/min.	
			300 rpm	1000 Rpm	300 rpm	1000 rpm	300 rpm	1000 rpm
30	40.55	5.5	825.13	1077.4	49.14	37.6	7.9	20.2
	51.33	5.7	993.46	1574.72	51.67	32.6	6.8	14.3
45	40.55	8.3	634.65	936.86	63.89	43.3	15.5	35
	51.33	8.6	886.31	1266.76	57.91	40.5	11.5	26.8
60	40.55	11.1	555.09	885.9	73.05	45.8	23.7	49.5
	51.33	11.8	608.47	1061.49	84.36	48.4	22.4	42.8
75	40.55	13.9	506.89	749.16	80	54.1	32.5	73.3
	51.33	14.4	547.01	920.53	93.84	55.8	31.2	61.8
90	40.55	16.6	478.69	634.85	84.71	63.9	41.1	103
	51.33	17.21	509.63	887.08	100.7	57.9	40	76.6

Table 3: Specific energy and UCS/SE for Granites at 300, and 1000 rpm and different loads

WOB, Kg	UCS, MPa	T, N.m	SE, MPa		$(UCS/SE)*10^{-3}$		ROP, mm/min.	
			300 rpm	1000 Rpm	300 rpm	1000 rpm	300 rpm	1000 rpm
90	74.88	22	6518.3	9656.8	11.5	7.75	4	9
	95.35	22.8	-	12867.3	-	7.41	-	7
120	74.88	29.4	4907.5	8603.3	15.3	8.7	7.1	13.5
	95.35	30.4	8188.3	1174	11.6	8.1	4.4	10.2
150	74.88	36.7	4103.3	8145.1	18.3	9.19	10.6	17.8
	95.35	38	-	10571.8	-	9.02	-	14.2
180	74.88	44.1	3461.3	7402.9	21.6	10.11	15.1	23.5
	95.35	45.6	-	9790.4	-	9.74	-	18.4
	74.88	52.2	2914.7	6466.8	25.7	11.58	20.9	31.9

210	95.35	53.2	4740.6	8793.6	20.1	10.84	13.3	23.9
300	74.88	76.1	-	-	-	-	-	-
	95.35	74.4	3636.7	-	26.2	-	24.8	-
390	74.88	98.9	-	-	-	-	-	-
	95.35	96.7	3417.2	-	27.9	-	34.3	-
480	74.88	121.7	-	-	-	-	-	-
	95.35	119	3004.8	-	31.7	-	48	-

Table 4: Average values of rate of penetration and specific energy at rotary speed 1000 rpm at different loads (WOB).

Weight On bit, Kg.	Limestones		Marbles		Granites	
	ROP, mm/min.	SE, Mpa	ROP, mm/min.	SE, MPa	ROP, mm/min.	SE, MPa
15	17.32	534.78	_	_	_	_
30	40.50	434.82	17.25	1326.06	_	_
45	65.72	387.64	30.9	1101.81	_	_
60	97.06	350.74	46.15	973.7	_	_
75	100.83	348.9	67.55	834.85	_	_
90	130.38	311.33	89.95	760.97	8	11262.05
120	_	_	_	_	11.85	10188.65
150	_	_	_	_	16	9358.45
180	_	_	_	_	20.95	8596.65
210	_	_	_	_	27.65	7630.20

Table 5: Average values of rate of penetration and specific energy at rotary speed 300 rpm at different loads (WOB).

Weight On bit, Kg.	Limestones		Marbles		Granites	
	ROP, mm/min.	SE, Mpa	ROP, mm/min.	SE, MPa	ROP, mm/min.	SE, MPa
15	9.1	299.05	-	_	-	_
30	21.64	244.79	7.35	909.3	_	_
45	36.8	214.58	13.5	760.48	_	_
60	50.66	196.13	23.05	581.78	_	_
75	65.5	144.68	31.85	526.95	_	_
90	87.80	127.15	40.55	494.16	4	6518.3

120	_	_	_	_	5.75	6547.9
150	_	_	_	_	10.6	4103.3
180	_	_	_	_	15.1	3461.3
210	_	_	_	_	17.1	3827.65
300	_	_	_	_	24.8	3636.7
390	_	_	_	_	34.3	3417.2
480	_	_	_	_	48	3004.8

From Tables 3and 4 for different rocks at 1000 and 300 rpm and at different loads, the marbles needed an amount of specific energy from (2.7 – 3.55) times that of limestones. The granite rocks needed specific energy from (13.19-14.80) times that of marbles needed, and from (36.17-51.26) times that of limestones needed to complete this operation at 90kg WOB.

II.RELATION BETWEEN UCS/SE AND ROP:

On the other hand, specific energy and the dimensionless index UCS/SE were detemined for the three types of rocks at the applied rotary speeds 300 and 1000 rpm and at different loads as given above in tables 1, 2, 3, 4, 5 and 6. The results of calculations at applied rotary speeds 300 and 1000 rpm and at different loads for new bit had been obtained. The rate of penetration is plotted against the dimensionless index UCS/SE for all rocks as shown in figures (3) and (4). About 48 points are plotted together represnting the sedimentary, metamorphic and igneous rocks from which, 28 points represent 5 limestones at six different loads and two different rotary speeds, 10 points represent marbles (2 types at five different loads and two different rotary speeds) and 10 points represent granites(2 types, one of them at eight different loads and 300 rpm and the other at five different loads and 1000 rpm).

Increasing the mechanical energy level on a bit (or increasing thrust load and rotary speed) will increase the penetration rate if there is a sufficient hydraulic energy available for bottom hole cleaning. Increasing thrust load and rotary speed, however, accelerate bit cutting and wear. In soft formations a doubling of either load or rotary speed will double penetration rate if sufficient horsepower is available.

In hard formations the load has to be sufficient to overcome the compressive strength of the rock, then increasing the load on bit by a factor of two doubles or more doubles penetration rate. The penetration rate is not linearly proportional to rotary speed in drilling hard formations because some finite time is required for a bit to fracture the rock . Accordingly, as can be seen from figure(3) increasing loads on bit increases penetration rate by high values in limestones and does not increase it for marbles and granites by the same values. It can be seen that there is no a distinct areas for the three types of rocks.

Figures (3, 4) represent the relationship between the new dimensionless index (UCS/SE) and the rate of penetration at 1000 and 300 rpm with all different applied loads respectively. From these figures, it can be seen that, at both higher (1000 rpm) rotary speed and lower (300 rpm) rotary speed with all different applied loads there was no any distinct areas for different rock categories, and the values of the rate of penetration (ROP) against the new index (UCS/SE) for all rocks are nearer from each other.

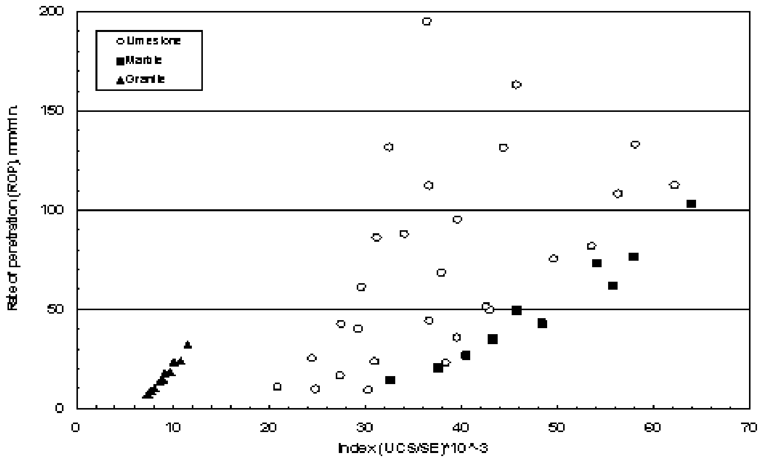

Figure (3) Relationship between UCS/SE and Rate of penetration for all rocks at different loads and rotary speed of 1000 rpm with new bit.

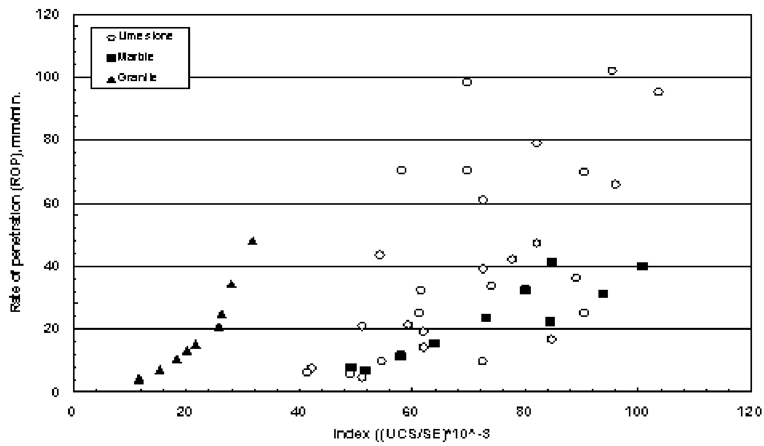

Figure (4) Relationship between UCS/SE and Rate of penetration for all rocks at different loads and rotary speed of 300 rpm with new bit.

Figure (5) shows that, when using rotary speed of 300 rpm and applying heavy different loads (WOB), we exclude the lower rates of penetration that correspond to lower loads (15 kg and 30 kg WOB). Then , plotting the relationship between the rate of penetration (ROP) against the dimensionless index (UCS/SE). It can be seen that, the three rock categories are lying into only two distinct zones, one for sedimentary rocks (limestones) and the other for both metamorphic and igneous rocks together (marbles and granites).

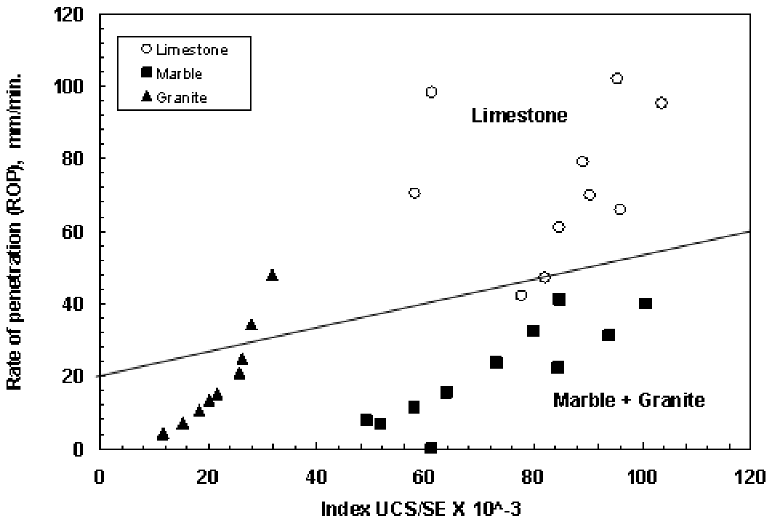

Figure (5) Relationship between UCS/SE and rate of penetration for all rocks at rotary drilling of 300 rpm and loads of 45, 60, 75, 90, 120, 150, 180, 210, 300, 390 and 480 kgf or new bit.

Increasing the rotary speed from 300 to 1000 rpm will increase the penetration rate by high values in case of limestones but it is not the same in case of marbles and granites as mentioned before. Then , plotting the values of rate of penetration (ROP) against the dimensionless index (UCS/SE) at the same loads but at rotary speed1000 rpm to see if the three rocks are too fall into distinct zones. Figure (6), shows that, the three rock categries are lying into three distinct zones.

It can be concluded that , when using both higher and lower rotary speeds (1000 and 300 rpm) with all applied different loads(WOB), there is no any distinct zones for the three rock categories But, at higher loads(WOB) and lower rotary speed(300 rpm) there are only two distinct zones one for sedimentary rocks (limestones) and the other for metamorphic and igneous rocks together(marbles and granites). Where as, at the same loads(WOB) and higher rotary speed(1000 rpm) the three types of rocks representing sedimentary, metamorphic and igneous are lying in three distinct zones.

CONCLUSIONS

- The specific energy for drilling in limestones, marbles and granites representing sedimentary, metamorphic and igneous rocks respectively by using diamond core drilling were obtained.
- The variation in specific energy for all rocks at applied different loads and different rotary sppeds were discussed. It is found that the marbles needed amount of specific energy from 2.7-3.55 times that of limestones. The granite rocks needed specific energy from 13.19-14.8 times that of marbles needed, and from 36.17-51.26 times that of limestones needed, according to the applied loads, to complete this operation.

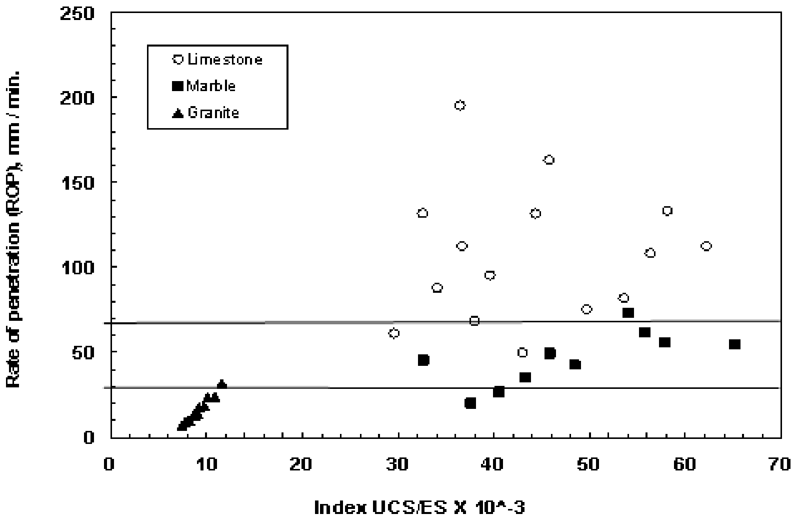

Figure (6) Relationship between UCS/SE and rate of penetration for all rocks at rotary drilling of 1000 rpm and loads of 45, 60, 75, 90, 120, 150, 180, 210, 300, 390 and 480 kg for new bit.

- Relationships between the rate of penetration (ROP) and the specific energy (SE) for all types of rocks at different loads and different rotary speeds were obtained and plotted in figures (1) and (2)
- The dimensionless index (UCS/SE) is calculated and illustrated in tables 1, 2, 3, 4, 5 and 6. The relationships between the rate of penetration (ROP) and (UCS/SE) were plotted at differen thrust loads and different rotary speeds as shown in figures 3, 4, 5 and 6.
- The results indicated that, at all applied loads (WOB) and both higher and lower rotary speeds (1000 and 300 rpm) there is no any distinct zones. But at higher applied loads (WOB) and lower rotary speed (300 rpm), the three groups of rocks are lying into only two zones one for sedimentary rocks (limestones) and the other for metamorphic and igneous rocks (marbles and granites). Where as, at the same higher applied loads (WOB) and higher rotary speed (1000 rpm), the three groups of rocks are lying into three distinct zones.

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بعض معاملات الحفر كوسيلة لتوقع أنواع الصخور المختلفة

في هذا البحث تم الحصول على النتائج المعملية لمعدلات الحفر في الصخور الرسوبية ممثلة بخمسة أنواع من الحجر الجيري وفى الصخور المتحولة ممثلة بنوعين من الرخام وكذلك في الصخور النارية ممثلة في نوعين من الجرانيت عن طريق استخدام ماكينة حفر معملية تقوم بعمل عينات باستخدام قواطع ماسية. وتم حساب الطاقة المستهلكة في الحفر لكل هذه الأنواع من الصخور وكذلك تم استنتاج العلاقات الرياضية التي تربط كل من: معدلات الحفر والطاقة لكل نوع من الصخور على حدة.

وللتعرف على أنواع الصخور التى يتم حفرها أمكن استنتاج معامل جديد هو عبارة عن قسمة مقاومة الصخر للضغط على الطاقة المستهلكة عند السرعات والأوزان المختلفة. ثم تم توقيع العلاقات بين هذا المعامل الجديد ومعدلات الحفر لكل الصخور موضع الدراسة عند سرعات مختلفة هى 300 لفة/دقيقة , 1000 لفة/دقيقة وأوزان مختلفة. من هذه العلاقات اتضح أنه عند استخدام كل الأحمال المختلفة والسرعات العالية والمنخفضة لم يكن هناك فصل واضح للأنوع المختلفة من الصخور وإنما كان هناك تداخل بينها. ثم بعد ذلك تم استبعاد الأحمال الصغيرة واستخدام الأحمال الكبيرة مع السرعة المنخفضة (300 لفة/دقيقة) وإعادة توقيع العلاقات بين المعامل الجديد ومعدلات الحفر، ومن هذه العلاقات أمكن التمييز بوضوح بين منطقتين فقط على الرسم واحدة تمثل الصخور الرسوبية والأخرى تمثل الصخور المتحولة والنارية معا. وعند استخدام نفس الأحمال الكبيرة ولكن مع السرعات العالية (1000 لفة/دقيقة) أمكن التمييز بوضوح بين ثلاثة مناطق على الرسم كل منها يخصص لنوع من الصخور الثلاثة. وعليه فإنه يمكن استخدام هذه الطريقة بالإضافة إلى بعض المعلومات عن الصخور من الفتات الناتج أثناء الحفر للتعرف على أنواع الصخور التى يتم الحفر فيها.