

## **OPTIMIZATION OF DIAMOND CORE BIT PERFORMANCE UTILIZING HIGH ROTARY SPEED IN DRILLING LIMESTONE ROCKS**

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*The principal factors that require in predicting drilling rates are the operating parameters of the drill bits and the penetrated rock characteristics. The effect of some mechanical and geological parameters on the penetration rate during drilling limestone rocks has been previously carried out by using a low rotary speed of 400 rpm. In this work, the drilling trials were carried out on the same rocks and by using the same machine and bit at high rotary speed of approximately 1200 rpm.*

*A fixed laboratory-diamond drilling machine was used to drill three types of limestone rocks utilizing rotational speed of 1200 rpm, and over a range of weights on bit (WOB). Operating parameters of the drill bit such as WOB, rate of penetration (ROP), torque and drilling specific energy (SE) were continuously monitored during the drilling trials. The effects of these parameters on the performance of the bit were examined. Relationships between WOB and both ROP, and SE were also described and the relationship between ROP and SE was also given. The obtained results were compared with that obtained by using a low rotary speed of 400 rpm. Increasing the rotary speed from 400 rpm to 1200 rpm increases the rate of penetration 3 times for Fresh limestone at the optimum weight on bit of 105 kg and this leads to decrease the specific energy. To obtain ROP of 0.5 cm/min as an example, the drilling machine needs S.E in Non-Fresh Limestone 3 times that for Fresh limestone and 2 times for Bedded limestone.*

### **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 influences [1,2].

The overall performance of any drill bit is complex and is affected by numerous factors which include operating parameters of the bit, formation properties, bit design and type, wear characteristics, drilling fluid properties and flow mechanics, hole characteristics, capacity of the drilling machine, time, climate and operator or crew efficiency. [3,4]

The effect of some mechanical and geological parameters on the penetration rate during drilling limestone rocks has been previously carried out by using a low rotary speed of 400 rpm [5]. In this work, the drilling trials were carried out on the same rocks and by using the same machine and bit at high rotary speed of approximately 1200 rpm.

The same diamond drilling machine was used to obtain cores from the same three types of limestone formation of different properties. The three types of rock were obtained from the Assiut cement company quarries, Egypt. The inside diameter of the bit used is 40 mm and the outside is 45 mm and the bit has four water way. Therefore, the bit has a set of drilling data for the rocks, at a particular rpm and applied weight on bit. A total of 75 drilling tests have been completed and a total of 6m has been drilled. [5,6]

Geological difficulties may have a high impact on the economics of underground construction project, especially when the chosen excavation system turns out to be unsuitable for the conditions encountered. Thus it can be argued that the geological and petrological characteristics of the rock mass should be evaluated with the same degree of effort as that for the geotechnical prognosis.[7,8]

PDC drill bit performance has been greatly improved over the past three decades by innovations in bit design and how these designs are applied [9]. Diamond bit drilling is one of the most widely used and preferable drilling techniques because of its higher rate of penetration and core recovery in the hardest rocks, the ability to drill in any direction with less deviation, and the ability to drill with greater precision in coring and prospecting drilling [10]

The goal of this work is to optimize the performance of diamond core bit in limestone formation with degrees of hardness at high rotary speed.

## PROPERTIES OF THE TESTED ROCKS

Three types from limestone {fresh limestone (rock No.1), bedded limestone (rock No.2) and non fresh limestone (rock No.3)} were collected from the quarry of Assiut Cement Company (cemex) Fig. ( 1 ).

It is clear, that the drilling parameters and tool wear are predominantly a result of the mineral content harder than steel, especially quartz, calcite, iron oxide, and the orientation of the bedding which affected in the rate of penetration [11].

Operating elements of drilling tools and machines in contact with rocks are exposed not only to mechanical stress but also to the friction between the surface of operating elements and rocks [12].

The most important physical and mechanical properties of the tested rocks such as density, porosity, compressive strength, tensile strength, and coefficient of internal friction ( $\mu$ ) were previously determined. Table (1) contains the average value for each respective test together with its stander deviation. The rocks were chosen as a testing medium because they represent a range of rocks, in terms of strength, for

mining and civil engineering. The data of drilling trials were carried out at drilling speed of 400 rpm represented in Table (2) [5].

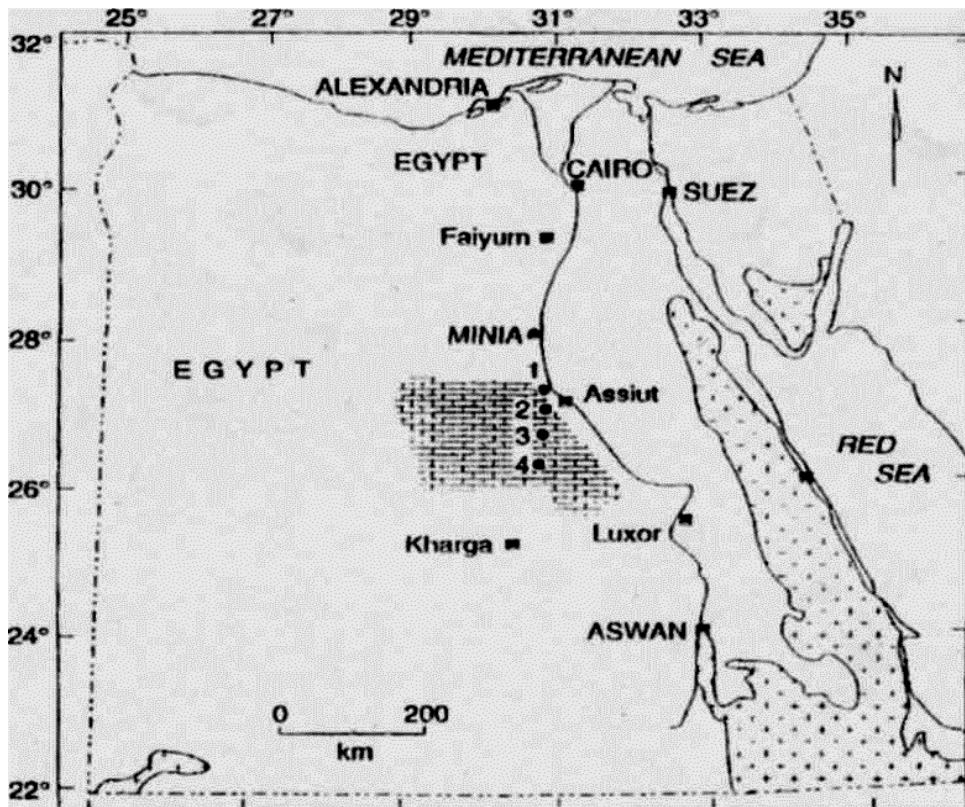


Fig.1. showing the location map of study area

**Table (1): The final values of physical and mechanical properties of the tested rocks**

Rock type	Compressive strength, MPa	Tensile strength, MPa	Density, g/cc	Porosity, %	Coefficient of friction.
<b>Rock 1</b>	137.8±11.57	17.14±1.2	2.06±0.032	12.87±0.94	0.95
<b>Rock 2</b>	271.82±9.97	36.4±0.66	2.30±0.030	9.06.1±0.72	1.02
<b>Rock 3.</b>	259.01±15.1	27.41±1.79	2.42±0.009	6.83±0.21	1.03

## EXPERIMENTAL WORK

In the present study, blocks are formed by diamond saw from each type of rock for the drilling test. Diamond core drilling is applied for the tests. The coring bit used has thin walled impregnated diamond type, inner diameter 40mm and the outer one 45mm. The drilling machine is a fixed laboratory type [13].

**Table (2): Experimental data for the operating parameters of the core drilling at 400 rpm.**

WOB, Kg	Fresh limestone (Rock1)			Bedded limestone (Rock 2)			Non fresh limestone (Rock 3)		
	ROP, mm/min	Torque, Nm	SE, MPa	ROP, mm/min	Torque, Nm	SE MPa	ROP, mm/min	Torque, Nm	SE, MPa
15	0.14	3.17	3576.58	-	-	-	-	-	-
30	2.07	6.34	483.677	-	-	-	0.0895	6.88	12139.54
45	2.58	9.51	582.100	0.30	10.21	5374.54	0.152	10.31	10711.55
60	3.2	12.68	625.758	0.50	13.62	4301.74	0.218	13.75	9960.55
75	2.5	15.85	1001.21	0.52	17.02	5168.84	0.2905	17.19	9344.73
90	2.5	19.02	1201.46	0.72	20.43	4480.98	0.492	20.63	6621.73
105	1.9	22.19	1844.33	0.75	23.83	4807.08	0.6063	24.06	6266.79
120	-	-	-	0.95	27.23	4526.49	0.7408	27.50	5862.31
135	-	-	-	0.85	30.64	5692.55	0.5966	30.94	8189.82
150	-	-	-	-	-	-	0.7378	34.37	7356.61

Data and conditions of drilling experiments and rock under tests were recorded. Applied load, actual speed, length of borehole, time of drilling are recorded as results of drilling. This result is used to calculate the drilling rate, and the average drilling rate at specific load. Three trials were carried out for a particular weight on bit (WOB). Selection of the WOB range for the bit was made by applying minimum WOB where the bit was just capable of drilling the rock and maximum WOB just below the point where the drill commenced to stall or showed "distressed" drilling. Ten WOB increments for each rock were selected between this limit [5].

All drilling trials were carried out at drilling speed of 1200 rpm motor speed. The experimental data of the operating parameters are presented in Table (3).

**Table (3) - Experimental data for the operating parameters of the core drilling at (1200 rpm).**

WOB, Kg	Fresh limestone( Rock1)			Bedded limestone( Rock2)			Non fresh limestone( Rock3)		
	ROP, cm/min	Torque, Nm	SE, MPa	ROP, cm/min	Torque, Nm	SE, MPa	ROP, cm/min	Torque, Nm	SE, MPa
30	2.5	6.34	1201.45	1.12	6.81	2880.63	-	-	-
45	3.6	9.51	1251.52	1.60	10.21	3023.18	-	-	-
60	4.5	12.68	1224.95	1.63	13.62	3958.65	0.2923	13.75	22462.75
75	6.0	15.85	1251.52	2.09	17.02	3858.08	0.36921	17.19	22622.04
90	8.1	19.02	1112.45	1.81	20.43	5347.47	0.5126	20.63	19164.05
105	10.8	22.19	973.40	1.66	23.83	6801.02	0.756	24.06	14998.24
120	14.2	25.365	846.26	-	-	-	1.7925	27.50	7278.43
135	-	-	-	-	-	-	1.3666	30.94	10699.37
150	-	-	-	-	-	-	0.4685	34.37	35398.11

## RESULTS AND DISCUSSIONS

Effects of both weight on bit (WOB), rotary speed (RPM), and the rock properties on rate of penetration at rotary speed of 1200 rpm were discussed below:

### **a) Effect of both WOB and Rotary Speed on Rate of Penetration:**

Effect of weight on bit (WOB) on the rate of penetration (ROP) in the three types of rocks is given in figures (2), (3) and (4). From these figures it is clear that, the increasing of the weight on bit (WOB) produces an increase in the rate of penetration (ROP) up to a maximum point. However, from the experimental data a further increase in weight on bit (WOB) causes little increase, or even a decrease in the rate of penetration (ROP) as in the case of drilling fresh limestone at 400 rpm.

The optimum load (WOB) is the weight which gives maximum value of the penetration rate (ROP) for rock drilling. From Fig. (2) For fresh limestone (rock No.1), at 60 Kg (WOB) the ROP is 3.2 which the maximum value of ROP at rotary speed 400 rpm. Where as at 120 Kg (WOB) the ROP was 14.2 cm/min at rotary speed of 1200 rpm. If we compare between ROP in the two cases ( at 400 rpm and 1200 rpm ) we find that the ROP at 1200 rpm will be from 1-6 times more than that at 400 rpm.

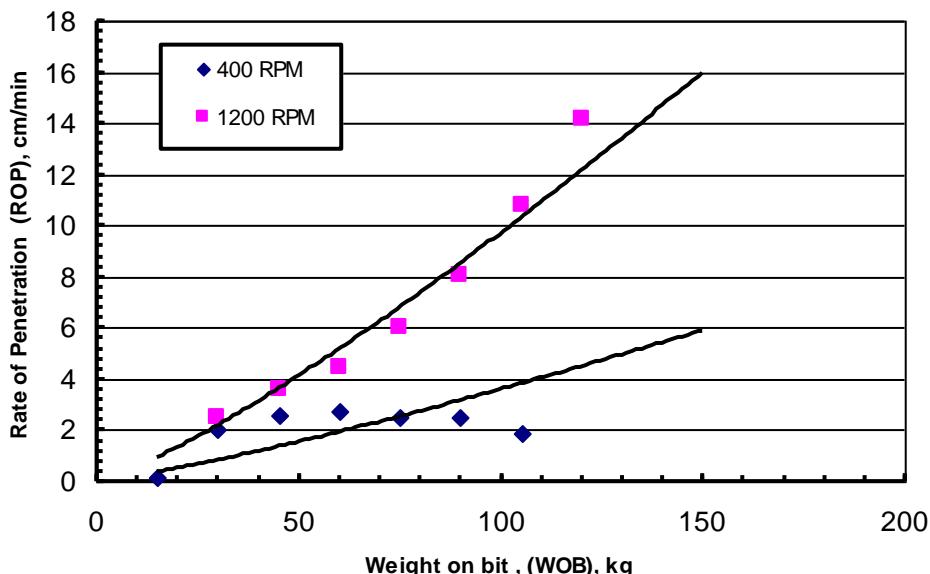


Fig. (2) Relation between (WOB) and (ROP) for Fresh Limestone (Rock No. 1) at rotary speed of 400 and 1200 RPM.

From Fig. (3) for bedded limestone (rock No. 2), the maximum value of ROP was 0.95 cm/min at WOB 120 Kg. for rotary speed 400 rpm, the maximum value of ROP was 2.09 cm/min at WOB 75 Kg for rotary speed 1200 rpm.

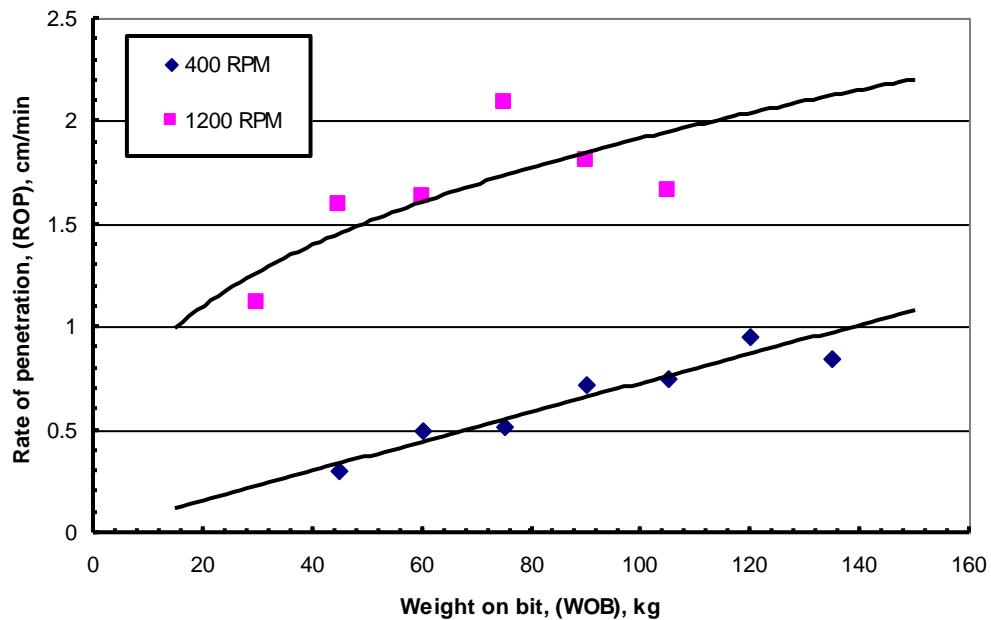


Fig. (3) Relation between (WOB) and (ROP) for **Bedded limestone** (Rock No. 2) at rotary speed of 400 and 1200 RPM.

If we compare between the two cases we will find that the ROP at 105 as an example for rotary speed of 400 rpm was 0.75cm/min where as for rotary speed of 1200 ROP was rpm1.66 cm/min. The ROP is from (1-4) times more for 1200 rpm than that for 400 rpm.

Figure (4) For non fresh limestone ( rock No. 3 ), the maximum value of ROP was 1.79 cm/min at WOB 120Kg for the rotary speed 1200 rpm where as the maximum value of ROP was 0.74 cm/min at 120Kg for rotary speed of 400 rpm. This mean the ROP is about 2.5 times more at 1200 rpm than that at 400 rpm for the same WOB.

From the three figures ( 2,3and 4) we can concluded that increasing rotary speed from 400 rpm to 1200 rpm increase the rate of penetration for all rocks. The increasing in ROP was graduate from the less value in case of non – fresh limestone to the high value in case of fresh limestone and the ROP in case of bedded limestone was found to be in between. This reflects the effect of hardness on the ROP. The ROP proportional inversely with rock hardness. We can concluded at load of 105 Kg WOB and 1200 rpm, the rate of penetration in fresh limestone is about 7and 14 times more than of the bedded and non fresh limestone respectively at 400 figures (2, 3, 4)

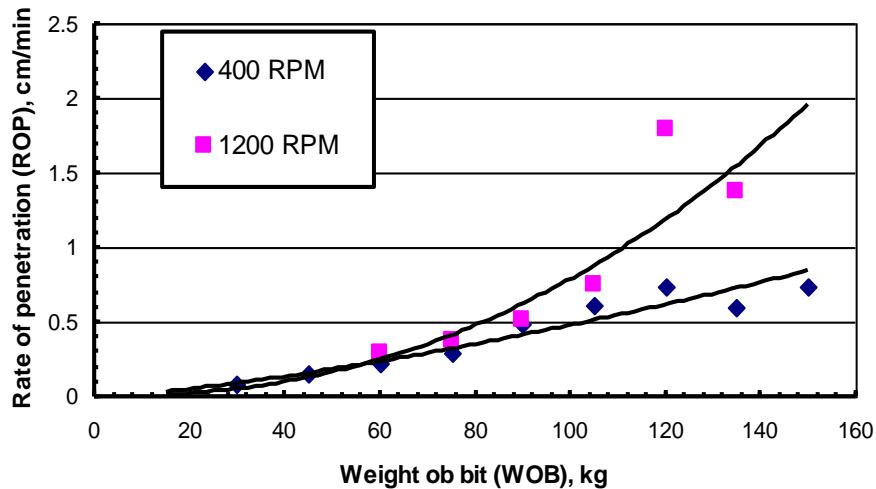


Fig. (4) Relation between (WOB) and (ROP) for Non-Fresh Limestone.  
(Rock No. 3) at rotary speed of 400 and 1200 RPM.

### b) Effect of WOB on Specific Energy at Different Rotary Speed:

A very good indication of how well a bit performing in a particular rock formation is given by a study of the drilling specific energy. Specific energy (SE) may be defined, as the energy required for removing a unit volume of rock; it may use any consistent set of units [10, 14, 15, 16, and 17]

From Fig.(5) it can be seen that the optimum WOB which give the lower value of specific energy is 30 kg for drilling in Fresh limestone at rotary speed of 400 rpm whereas WOB of 120 kg is the optimum WOB when drilling with 1200 rpm.

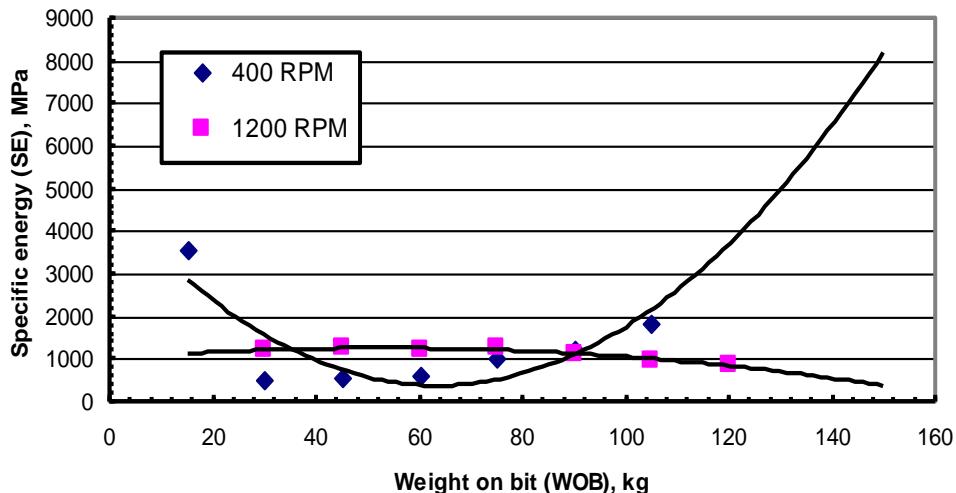


Fig. (5) Relation between (WOB) and (S.E.) for Fresh Limestone  
(Rock No. 1) at rotary speed of 400 and 1200 RPM.

From Fig. (6) it can be seen that the optimum WOB which give the lower value of specific energy is 60 kg for drilling in Bedded limestone at rotary speed of 400 rpm where as WOB of 30 kg is the optimum WOB when drilling with 1200 rpm in Bedded limestone (Rock No. 2).

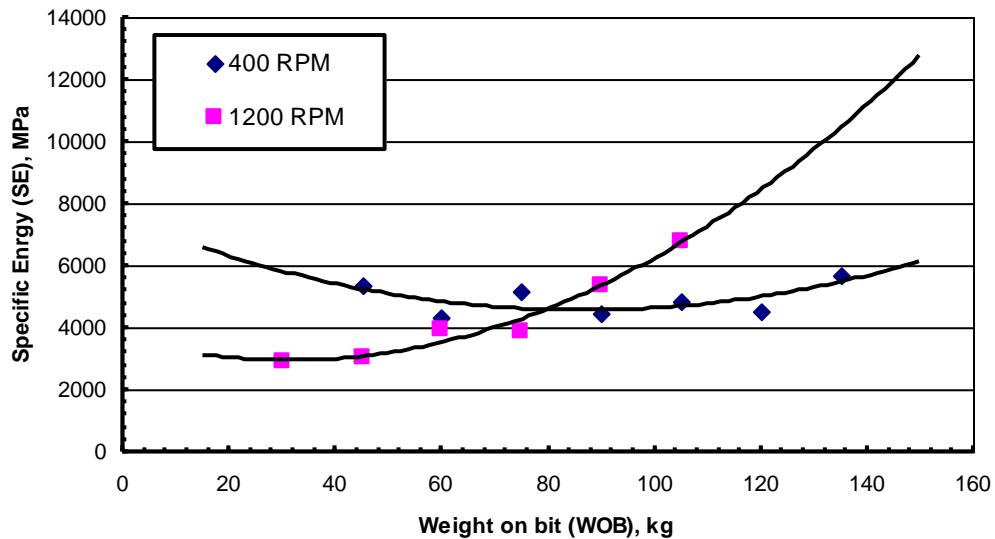


Fig. (6) Relation between (WOB) and (S.E) for Bedded Limestone (Rock No. 2) at rotary speed of 400 and 1200 RPM.

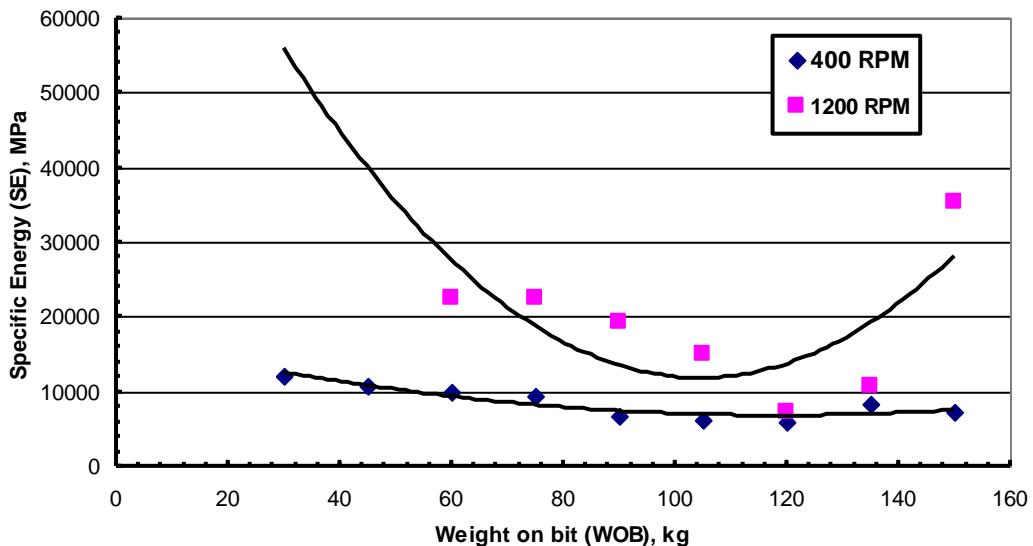


Fig. (7) Relation between (WOB) and (S.E) for Non-Fresh Limestone (Rock No. 3) at rotary speed of 400 and 1200 RPM.

From Fig. (7) it can be seen that the optimum WOB which give the lower value of specific energy is 120 kg for drilling in Non-Fresh limestone at rotary speed of 400 rpm and of 1200 rpm in Non-Fresh limestone (Rock No. 3).

Figures 5, 6 and 7 show that at low WOB, SE increases for the three types of rock and increasing WOB is associated by decreasing in SE for a certain limits, then decreasing WOB increases SE. WOB that give the lower value of the SE is the optimum WOB. From the results it can be seen that the optimum WOB is 120 kg for drilling in Fresh limestone and 30 kg for drilling in Bedded limestone and 120 kg for drilling in Non-Fresh Limestone.

### c) Relation between (ROP) and (S.E.).

From fig (8) at rotary speed 400 rpm ,it can be seen that SE is proportional inversely with ROP in all tested rocks , but Fresh limestone requires less SE than Bedded limestone and Bedded limestone requires less SE than Non-Fresh Limestone [5].

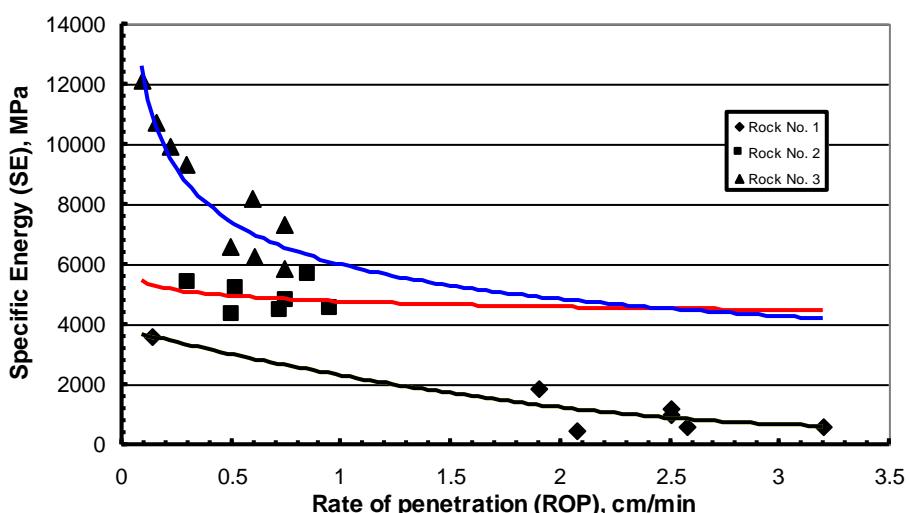


Fig. 8 Relationship between rate of penetration (ROP) and specific energy (SE) for the three rocks at 400 RPM.

Figures (9, 10 and11) Show the relationships between rate of penetration and specific energy for fresh limestone ( rock No. 1), bedded limestone (rock No. 2) and non-fresh limestone (rock No. 3) at 1200 rpm. It can be seen that SE is proportional inversely with ROP in fresh limestone and non-fresh limestone but it does not be found in case of bedded limestone that is because of bedding which is oriented parallel to drilling axis (Fig.10).

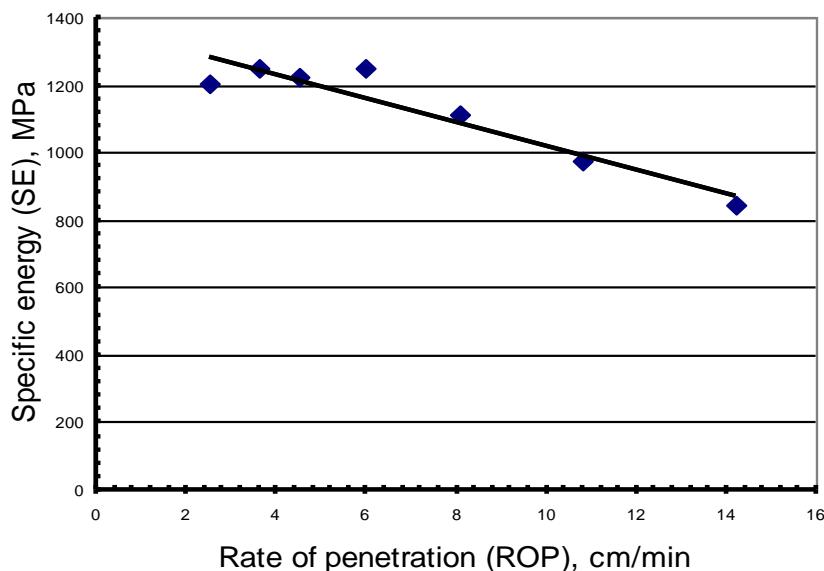


Fig. 9 Relationship between rate of penetration and specific energy for fresh limestone (rock No. 1) at 1200 rpm.

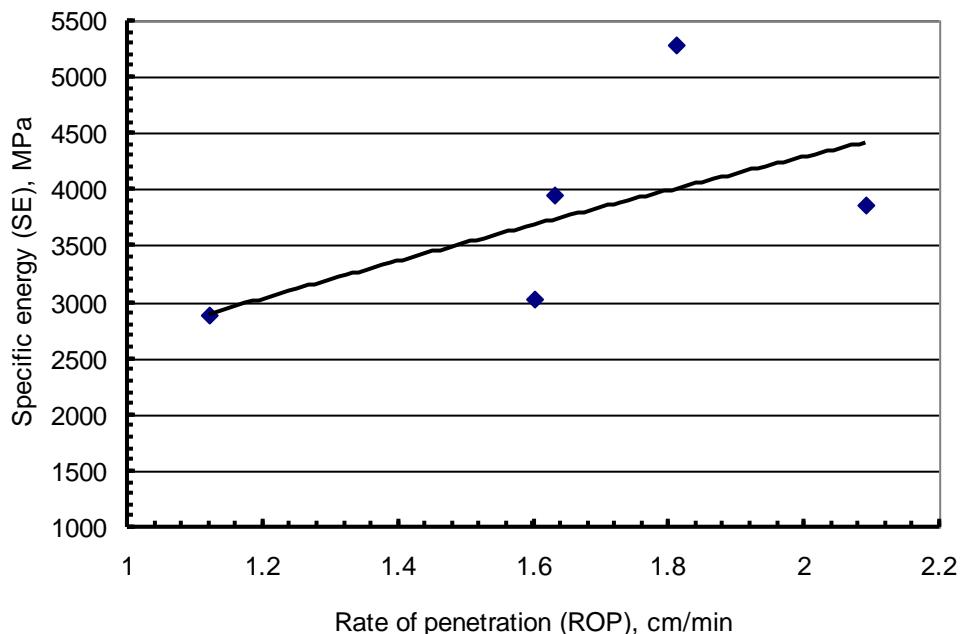


Fig. 10 Relationship between rate of penetration and specific energy for bedded limestone (rock No. 2) at 1200 rpm.

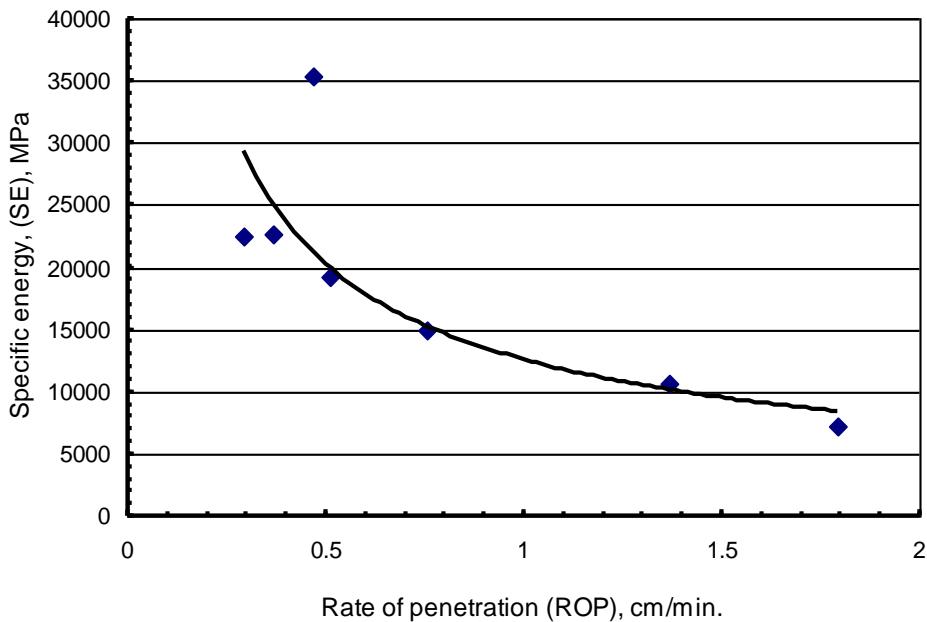


Fig. 11 Relationship between rate of penetration and specific energy for non-fresh limestone (rock No. 3) at 1200 rpm.

#### d) Effect of Rock Properties on ROP at 400 and 1200 rpm

Increasing the rotary speed from 400 rpm to 1200 rpm does not change the effect of geological parameters on the ROP. Fresh limestone has highest value of ROP because it contains the lowest iron oxide and quartz; on the other hand, Non-Fresh Limestone has the lowest value of ROP, because it contains the lowest percentage of iron oxides and quartz. By the same way we predict that Bedded limestone is lower than Non-Fresh Limestone in penetration rate , but , the experimental data show that it is higher than it, that is because of bedding which is oriented parallel to drilling axis.

There were a correlation between the porosity of the rock and technical parameters. Accordingly we found that Fresh limestone has the highest value of penetration rate and high value of porosity (12.87%). Bedded limestone and non-fresh limestone having lower penetration rate and porosity (9.06%, 6.083%) respectively than fresh limestone.

## CONCLUSION

- 1- The ROP will be from ( 1-6 ), ( 1-4 ) and 2.5 times more at 1200 rpm than that at 400 rpm for drilling in fresh limestone, bedded limestone and non-fresh limestone respectively.
- 2- We can concluded at load of 105 Kg WOB and 1200 rpm the rate of penetration in fresh limestone is about 7and 14 times more than of the bedded and non fresh limestone at 400 rpm respectively.

- 3- At low WOB, SE increases for the three types of rock and increasing WOB is associated by decreasing in SE for a certain limits, then decreasing WOB increases SE. WOB that give the lower value of the SE is the optimum WOB. From the results, it's found that the optimum WOB is 30 kg for drilling in fresh limestone and 60 kg for drilling in Bedded limestone and 120 kg for drilling in Non-Fresh Limestone for the two cases at 400 and 1200 rpm.
- 4- S.E is proportional inversely with ROP in all tested rocks, but Fresh limestone requires less S.E than Bedded limestone, and Bedded limestone requires less S.E than Non-Fresh Limestone. The lower value of S.E indicates the bit is more efficiency. To achieve a low S.E it is obviously advantageous to have as high a penetration rate as possible. To obtain ROP of 0.5 cm/min as an example, the drilling machine needs S.E in Non-Fresh Limestone 3 times that for Fresh limestone and 2 times for Bedded limestone.
- 5- This study achieved the true of ROP proportional directly with porosity. Increasing of ROP in case of fresh limestone is associated by an increase in porosity (12.87%) and vice versa. Decreasing of ROP in case of bedded and non-fresh limestone is associated by decrease in porosity (9.06% and 6.08%) respectively.

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## تحسين اداة الة الحفر الماسية باستخدام سرعات عالية للحفر في صخور الحجر الجيري.

العوامل الرئيسية المطلوب تحديدها خلال عمليات الحفر هي معايير تشغيل الة الحفر وخصائص الصخور التي سوف يتم حفرها وقد تم سابقا دراسة تأثير العوامل الميكانيكية و الجيولوجية على معايير تشغيل الة الحفر اثناء الحفر في صخور الحجر الجيري تحت سرعة منخفضة تعادل 400 لفة / دقيقة.

وفي هذا البحث تم الدراسة على الحفر في نفس صخور الحجر الجيري وبين نفس نوعية ماكينة الحفر ولكن مع زيادة سرعة الحفر الى 1200 لفة / دقيقة بواسطة ماكينة الحفر المعملية ذات قواطع الماس وتحت تأثير اوزان مختلفة وتم قياس عوامل التشغيل الخاصة بالة الحفر والتي ل لها تأثير عليها مثل الحمل الواقع عليها و معدل الحفر و عزم الدوران و الطاقة المستهلكة في عملية الحفر.

ومن خلال الدراسة تم عمل علاقة بين معدل الحفر والطاقة المستهلكة في الحفر و تم مقارنة هذه النتائج تحت تأثير سرعة 1200 لفة / دقيقة ومقارنتها مع الدراسة السابقة التي تمت تحت تأثير سرعة اقل وهي 400 لفة / دقيقة وجد ان معدل الحفر يزداد 3 مرات في الحجر الجيري النقي تحت حمل 105 كجم ويؤدي هذا الى تقليل الطاقة المستهلكة.

من الدراسة وجد انه عند معدل 0.5 سم/دقيقة مثلاً أو كمثال نجد إن الطاقة المستهلكة في الحفر في الحجر الجيري الغير نقى تعادل 3 مرات قدرها في الحجر الجيري النقى وتعادل مرتين في الحجر الجيري الطباقي .