Superintendenceof Bit Dullness Using a New Technique for Nasriya Oil Wells

Rafid Kadhim Abbas
Faculty of Engineering,University of Al-Qadisiya, , Al-Diwaniya city, 58002, Iraq,
Rafid.1972@gmail.com , Rafid.Abbas@qu.edu.iq

Abstract

The present researchconcentrates on the surveillance of the bit tooth wear using a new formula that merged the classic formula of specific energy produced by Rabia with the equation of three-abrasive wear found by Rabinowicztaking into account the effect of lithology of the rock formation as well as the materials that the drill bits are made from.Drilling parameters also have significant influence on the predicted wear and therefore, they have to be involved in the prediction of the drill bit tooth dullness.The new attempt is applied on threedeep oil wells in Nasriya field southern Iraq.

Three body abrasion phenomena took place while the bit is drilling the rock formations, therefore, it should be used as a concept for the wear prediction. The ratio of hardness of the rock over that of the bit has a great effect on the determination of the bit tooth wear. In this work, a new formula of specific energy is compared with the specific energy produced by Rabia along with the depth in the presence of the actual bit tooth wear taken from the bit records ofthreedeep wells inNasriya field. This research is done to find a reliable formula for the prediction of bit tooth dullness, especially that relevant researcheson Nasriyawells areunavailable in the literature.

Keywords: bit dullness; bit wear; worn bits; three body abrasive wear.

الخلاصة

هذا البحث يركز على مراقبة تآكل أسنان الحافرة بأستخدام صيغة جديدة و التي دمجت الصيغة الكلاسيكية لصيغة الطاقة المحددة المنتجة من قبل ربيعة مع معادلةتآكل الجسم الثلاثية التي وجدت من قبل رابينوفج مأخوذ بنظر الاعتبار تأثير التسلسل الطبقي للطبقات الصخرية و كذلك تأثير المواد التي تدخل في صنع الحافرات. عوامل الحفر ايضا لها تأثير مهم على التآكل الذي يتم التنبؤ ، لذلك فهي ايضا يجب تضمينها في التنبؤ بتلف أسنان الحافرة. المحاولة الجديدة تم تطبيقها على ثلاثة آبار نفطية عميقة في حقل الناصرية جنوبي العراق.

ظاهرة تآكل الجسم الثلاثية تاخذ حيزا عندما تحفر الحافرة للصخور، لذلك يجب استخدامها كمبدأ في التنبؤ بالتلف. ان نسبة الصلادة الخاصة بالصخور على صلادة الحافرة لها تأثير عظيم على تحديد تلف الحافرة.. في هذا البحث صيغة جديدة للطاقة المحددة تم مقارنتها مع الطاقة المحددة التي انتجت من قبل ربيعة على طول العمق بوجود التآكل الحقيقي لاسنان الحافرة المأخوذ من سجلات الحافرة لثلاثة آبار عميقة في حقل الناصرية. هذا البحث تم عمله لايجاد صيغة موثوق فيها للتنبؤ بتآكل اسنان الحافرة ، خصوصا و أن بحوث مماثلة لابار الناصرية هي غير متوفرة في الأدبيات.

الكلمات المفتاحية : تلف الحافرة ، تآكل الحافرة ، الحافرات التالفة ، تآكل القشط.

1. Introduction

It is crucially important to predict the bit wear (dullness) to avoidconsuming extra money and time during the drilling operation and therefore, significant savings could be achieved. Classic specific energy technique is used for this purpose, but still nowadays considered unreliable approach unless it should be used with other techniques such as well logs, cost per foot (*CPF*) and other geological methods.

In drilling oil and gas wells, roller-cone bits with conical-shaped teeth are now widely used due to their favorable durability and cost compared to PDC bits, however generally speaking the prospective rock formation to be drilled plays an important role for bit durability. The state of the bit is assessed according to the status of the tooth and the bearings holding the cones of the bits. Roller-cone (tri-cone) bits are classified mainly into two categories; milled tooth bits and insert bits. Steel is the main content of Milled tooth bits, whereasTungsten- Carbide (*TC*) alloy is the main component for insert bits. As drilling progresses the bits become worn and hence drilling efficiency reduces. The traditional technique for diagnosing the status of the bit wear is by monitoring the Specific Energy (*SE*) simultaneously with the rate of penetration (*PR*) against depth(**Pessier** and **Fear,1992**, **Dupriest** and **Koederitz,2005**, **Rabia *et.al.,* 1986**,**Farrelly** and **Rabia,1987** and **Chen *et.al*., 2014**).

Waughman *et.al.*, 2002, 2003 studied the real-time specific energy (*SE*) as a reliable technique for pulling out worn bits based on the plot of *SE* against depth. **Waughman *et.al*.,2003** found that when drilling shale formations, the behavior of *SE* was different and gave high values of *SE*due to bit balling. Bit balling is the phenomenon where the shale particles absorb the drilling fluid making the shale particles swelled and accumulated at the bit head showing misleading interpretations of*SE*, therefore, when penetrating shale and or formations relevant to shale such as marl formations, more effective reliable techniques should be used for the purpose of evaluating the status the bit to avoid any misleading interpretation caused by *SE*.Geological information of the drilled formations (lithology) as well as well logs are the most widely methods used for validation.

Hydrocarbon drill bits are classified into two major categories: roller-cone and shear bits. The first type has usually three rotating cones enhanced by bearings (tri-cone bits), whereas the latter has no rotating parts such as Polycrystalline Diamond Compact (*PDC*) bits. Currently roller cone bits are used more than PDC bits and account approximately 90% of the market demand (**Imhoff *et.al.*, 1985**).

Each cone of the roller bits has rows of teeth that are made from steel and hence the bits are called Milled bits or the teeth are manufactured from Tungsten-Carbide (*TC*) and hence it is called insert bits or sometimes the cutting teeth are made from synthetic diamond as existed in PDC bits. Figure (1) illustrates the main existing types used currently in hydrocarbon drilling operations.

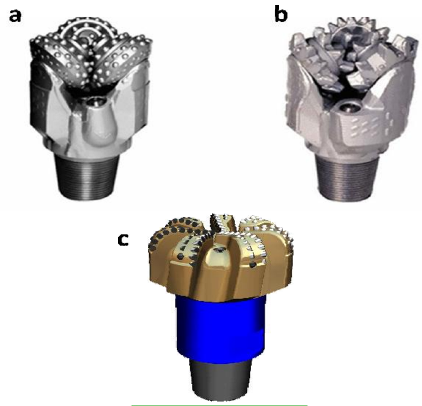

Fig. (1) Hydrocarbon drill bits: (a) Insert bit, (b) Milled steel bit and (c) PDC bit (Lin, 2013).

Roller-cutter bits mostly worn due to the dullness of their teeth. Dullness referred to the flatness of the teeth (wear). The wear of the drill bit teeth attributed to many reasons mainly: high temperature causing geothermal degradation, abrasive wear and excessive weight on bit, causing high vibration leading to impact wear (**Bhushan, 2000**).

Reed Tool Company,1999 for oil and gas drill bit manufactory classified the bit tooth wear as fraction of eight according to the International Association of Drilling Contractors (*IADC*)as for a brand new insert, the wear will be 0 out of 8, whereas for a totally destroyed insert will be 8 out of 8 or 1.0. Figure (2) demonstrates the dulling (wear) fraction for roller-cone and PDC bits.

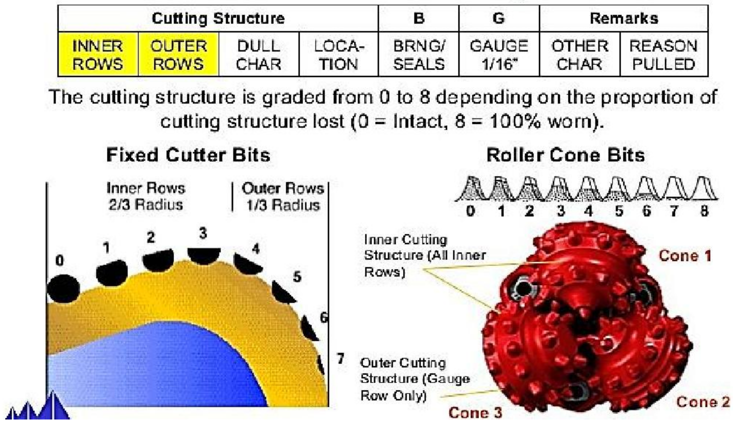

Fig. (2) Bit tooth wear (Reed Hycalog,1999).

2. ACQUISITION of DATA

Data required for the further calculations in this paper data has been collected from bit records of threedeep wells in Nasriya field **(Nasriya #1 , #2 and #3)** contracted by Iraqi South Oil Company (ISOC). Litholgical information for these two above wells are unavailable, therefore, formation lithology of the specific well were taken from an adjacent well (Nasriya #4).Figure (3) illustrates the bit record data for well Nasriya #1.

WELL NO. NS-1
BIT RECORD

COUNTRY : IRAQ	FIELD : Nasrvia	STATE: Nasriya	SECTION:	TOWNSHIP:	RANGE :	LOCATION:	WELL NO.: NS-1
CONTRACTOR : I.S.O.C	RIG :	OPERATOR :		TOOLPUSHER :		SALESMAN :	

NO	SIZE	MAKE	TYPE	JET	SERIAL	DEPTH OUT	METERS DRILLED	HRS	WT. TON	RPM	PUMP PRES. KG/CM²	FLOW RATE L/MIN	SPM	DULL COND. T	B	G	OTHER
17	12 1/4	Hughes	X1G	2*14*16	810 DK	2112	15	4 1/2	15/18	120	196	2400	45-48	1	1	-	-
18	12 1/4	Hughes	X1G	2*16*14	810 DK	2180	68	16 3/4	15/18	110	174	2550	48-43	5	5	-	-
19	12 1/4	Hughes	X1G	2*16*14	814 DK	2264	84	35 1/4	15/18	110	180	2550	48-43	7	6	o	-
20	12 1/4	Hughes	XV	2*16*14	292 HK	2337	73	34 3/4	16/18	110	180	2550	48-43	5	5	o	-
21	12 1/4	Hughes	XV	2*16*14	294 HK	2394	57	33 1/2	18	110	176	2550	48-43	4	2	o	-
22	12 1/4	Hughes	XDV	2*16*14	156 JK	2446	52	25 3/4	18	110	176	2550	48-43	8	5	o	-
23	12 1/4	Hughes	J33	2*16*14	463 RL	2489	43	13	18/20	60/70	176	2550	48-43	1	6	o	-
24	12 1/4	Hughes	J33	2*16*14	Y66 RL	2622	133	56 3/4	18/20	60/70	178	2550	48-43	8	8	o	-
25	12 1/4	Hughes	XDD	2*16*14	589 JK	2660	38	14 1/2	18	120	178	2550	48-43-	6	2	o	-
26	12 1/4	Hughes	J33	2*16*14	603 FL	2695	35	18	20	55	176	2500	48-41	2	6	o	-
27	12 1/4	Hughes	XDV	2*16*14	590 JK	2725	30	12	20	120	176	2500	48-41	6	4	o	-
28	12 1/4	Hughes	XDV	2*16*14	145 JK	2757	32	16 1/4	20	120	176	2500	48-41	6	2	o	-
29	12 1/4	Hughes	XDV	2*16*14	152 JK	2796	39	14 1/4	18/20	120	175	2450	45-41	6	2	o	-
30	12 1/4	Hughes	XDV	2*16*14	588 JK	2827	31	14	18	120	175	2450	45-41	8	4	o	-
31	12 1/4	Hughes	XDV	2*16*14	135 JK	2861	34	15 4/5	18	120	175	2450	45-41	6	4	o	-
32	12 1/4	Hughes	XDV	2*16*14	504 JK	2879	18	3 4/5	18	120	175	2390	44-40	6	2	o	-
33	12 1/4	Hughes	J33	2*16*14	602 RL	2935	56	37	18	55	175	2390	44-40	4	6	o	-
34	12 1/4	Hughes	XDV	2*16*14	159 JK	2957	22	13	18	120	175	2390	44-40	4	4	o	-
35	12 1/4	Hughes	J33	2*16*14	464 RL	2981	24	29 1/4	18	120	175	2390	44-40	2	6	o	-
36	12 1/4	Hughes	XDV	2*16*14	146 JK	3010	29	11 3/4	18	120	175	2390	44-40	8	4	o	

Fig.(3) Bit record of well Nasriya #1 (Obtained from Iraqi South Oil Company, ISOC).

Figure (4) shows the lithology of an offset well (Nasriya #4) which is adjacent to wells Nasriya #1 and #2.

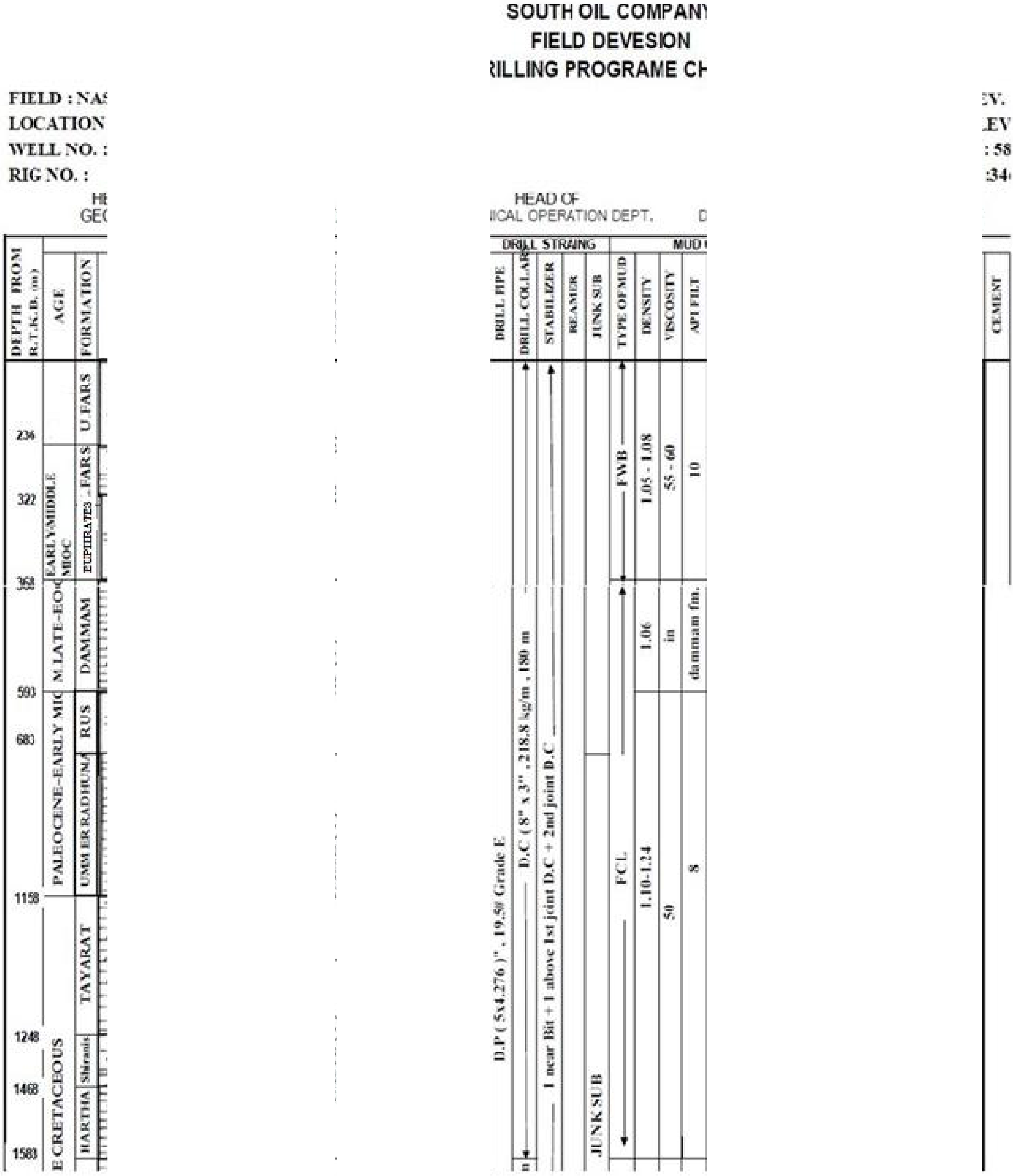

Fig. (4)Formation lithology combined with other information while drilling well Nasryia #4
(Obtained from Iraqi South Oil Company, ISOC).

3. THEORY

The main wear mechanism occurs in oil drill bit teeth is three-body abrasive wear (**Bhushan, 2000** and **Gonzalez *et.al.*, 2011**). Three-body abrasion refers to particles trapped between two surfaces that remove the material from the top or bottom surface or both, whereas two-body abrasion refers to the hard surface that slides over the soft one removing the material from the soft surface (**Gates, 1998**).

Figure (5) demonstrates the phenomenon of two and three body abrasive wear (**JGS, LLS, 2014**).

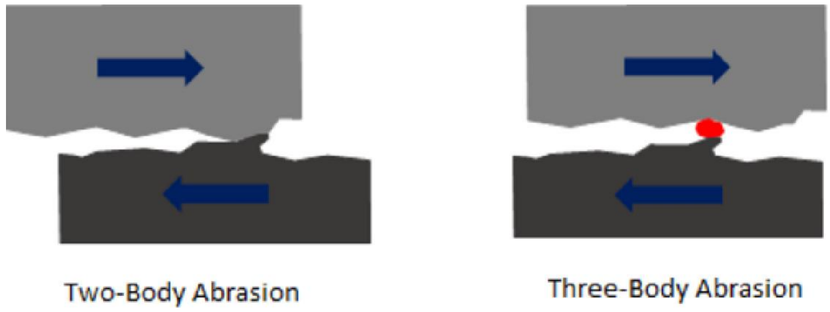

Fig. (5)Main wear mechanisms occurs in drill bit teeth (courtesy of JGS, LSS,2014)

The status of the drill bit influences the direct energy in the drill string. When bit tooth wear occurs, rate of penetration decreases significantly resulting increase in the weight on bit and torque due to the energy dissipated as a result of the bit damage. Two main drilling parameters should be monitored during the drilling operation in order to decide when the drill bit must be pulled out the wellbore.

The determination of the dullness of the drill bit tooth is crucially important to maximize drilling efficiency and reduce economic losses. In the literature there were approaches for quantifying the wear of the drill bit tooth as many factors affecting the wear of the drill nits are rather complicated. However, the mechanical properties of the drill bit tooth were not taking into account that affects the value of the wear significantly; therefore the necessity appeared to find a new formula to forecast the bit tooth dullness with high reliability.

Rabinowicz,1977 suggested a formula for quantifying the volume of the abraded and the abrasive materials in the case of three-body abrasion as when the hardness of the abrasive and the abraded materials take into account, the resulting wear is considered three-body abrasion which differs that the case of two-body abrasion where only the hardness of the abraded material is considered .Functionalizsing Rabinowicz 's formula in the case of drill bit and the rock produces Equation (1) as follows:

$$V_w = \frac{F.\tan(\theta).X}{5.3\,H_W}\left(\frac{H_a}{H_W}\right)^{2.5} \qquad 0.8\,H_a < H_W < 1.25H_a \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

where $H_a$is the hardness of the bit and H_W ishardness of the rock being excavated (N/m^2), , F is the applied load (N), X is the sliding distance (m), θ is the abrasion angle and V_w is the volume of the material removed (m^3).

The distance (X) in Eq.(1) could be replaced in terms of the linear velocity (V_L) as V_L is equal to the sliding distance over the time.

Hence, in terms of the angular velocity, i.e.2πN. Therefore, the linear velocity (V_L) equals to 2πN× r or equals to πN×d.

where r is the radius of the drill bit (in), d is the diameter of the bit (in) and N is the rotary speed (rpm).

Hence, Eq.(1) could be re-written after the substitution of (πN×d× time) instead of the sliding distance (X). In addition, the exertedload (F) in Eq. (1) corresponds to the weight on bit (W). The resulting equation is as follows:

$$\boldsymbol{Rock\ wear\ rate}\ \left(\frac{V_W}{time}\right) = \frac{W.\tan(\theta).\pi N d}{5.3\ H_W}\left(\frac{H_a}{H_W}\right)^{2.5} \quad (2)$$

Rabia, 1985and **Rabia *et.al.,* 1986** used a new formula for the specific energy based on the drilling parameters without torque as shown in Eq. (3):

$$SE = 20\ \frac{W.N}{d.PR} \quad (3)$$

where W is the weight on bit (lb) , d is the diameter of the bit (in) , N is the rotary speed (rpm), PR is the penetration rate (ft/hr) and SE is expressed in lb.in/in^3 or psi.

In general, the specific energy defines as the energy required excavating a unit volume of rock. The basic of Eq.(3) is obtained from Eq.(4):

$$SE = \frac{Energy\ rate}{Volume\ rate\ of\ the\ rock\ being\ excavated} \quad (4)$$

Energy rate can be calculated from the following equation(**Rabia,1985**):

$$Enegy\ rate = W.r.2\,\pi.N \quad (5)$$

where W is the weight on bit (Kg) , r is the bit radius (mm) and N is the rotary speed (rpm).

Hence, a new formula could be obtained by merging the equation of rate volume of rock being removed into the specific energy equation by substituting (Eq.2) in the denominator of Eq.(4). The resulting formula is as follows:

$$SE = \frac{W(Kg).r(mm).2\,\pi.N}{\frac{W\,(N).\tan(\theta).\pi\,N.d(m)}{5.3\,H_W}\left(\frac{H_a}{H_W}\right)^{2.5}} \quad (6)$$

It is worth mentioning that the value of the abrasion angle (θ) in Equation (6) varies according to the location of the bit tooth being excavating the rock. According to the study of **(Nguyen** and **Van, 1995)**, the abrasion angle (θ) ranges between 45° and 0°. To simplify the solution of Equation (2), the value of θ is assumed to be 15°.

As the weight on bit and the diameter in the nominator have inhomogeneous units with those in the denominator. Therefore, conversion factors should be used. The final formula of specific energy (SE) in psi is shown in Eq.(7):

$$SE = \frac{28137.862\ \ H_W}{\left(\frac{H_a}{H_W}\right)^{2.5}} \quad (7)$$

where H_a is the hardness of the bit and H_W is hardness of the rock being excavated (N/m^2).

4. Methodology

As Equation (7) requires the determination of the hardness of the rock being excavated as well as the hardness of the material forming the tooth of the drill bit, therefore, it is crucially important to determine these two parameters. As mentioned previously that, the lithology of the formations being excavated is determined from the offset (adjacent) wells and consequently the corresponding type of the rock determined. Later, thehardness of the rock formations being drilled could be obtained from literature, while the hardness of the material forming the cutters of the drill bitis obtained from the literature (**Mouritz** and **Hutchings, 1991**, and **Gokhale, 2010**) as shown in Table 1.

Table 1 Main rock formations being penetrated with the corresponding hardness (**Mouritz**and **Hutchings, 1991** and **Gokhale, 2010**)

Main Rock Formation	*Hardness (GPa)*
Sandstone	10.79
Limestone	1.079
Shale	2.45
Dolomite	1.961
Anhydrite	1.569
Conglomerate	1.17

It is worth mentioning that the IADC classification is considered for the determination of the type of the drill bit being used during the drilling operation based on its commercial code (**Security, 1985**). Accordingly, the hardness of the material forming the cutters of the drill bit is determined.

As previously shown in Figure (1a, 1b), tri-cone bit is either insert or steel. The approximate hardness of the cutters of the insert or TC bit is 15 GPa (**Osipov *et.al.*, 2010**), whereas the hardness of the teeth of the steel (milled) bit is about12.95 GPa(**Mouritz** and **Hutchings, 1991**).

From the obtained bit record data, all the bits used are roller-cone bits. Table 2 demonstrates the drill bit manufacturer with the corresponding IADC drill bit code along with the hardness for bit teeth for well Nasryia#1 in Nasryia field south of Iraq. Table 3 shows the rock formations being drilled and the corresponding hardness in GPa, along with the drilling parameters**.**

Table 2 Roller-cone bits being penetrated well Nasryia#1south of Iraq **(part of the data)**

Depth (m)	*Drill Bit Make*	*Tri-Cone Code*	*Tri-Cone Type*	*Drill Bit Cutter hardness (GPa)*	*Bit tooth condition (0-8)*
0-530	HUGHES	OSC-3AJ	Milled-tooth	12.95	3
530-624	HUGHES	OSC-3AJ	Milled-tooth	12.95	5
624-674	HUGHES	OSC-3AJ	Milled-tooth	12.95	6
674-830	HUGHES	OSC-3AJ	Milled-tooth	12.95	4
830-1082	HUGHES	OSC-3AJ	Milled-tooth	12.95	3
1082-1287	HUGHES	OSC-3AJ	Milled-tooth	12.95	4
1287-1454	HUGHES	OSC-3AJ	Milled-tooth	12.95	3
1454-1538	HUGHES	OSC-3AJ	Milled-tooth	12.95	4

Table 3 shows a sample of the main drilling parameters taken from the bit record of well Nasryia#1 as well as the rock formations being penetrated with their hardness.

Table 3 Rock formations with the corresponding hardness along with the drilling parameters of well Nasryia#1 in Southern Iraq

DepthDrilled (m)	***Rock Formation (GPa)***	***Formation Hardness (GPa)***	***Bit Dia. (in)***	***Weight on Bit (Ton)***	***Rotational Speed (rpm)***	***Meters drilled (m)***	***Time (hr)***	***Penetration Rate (m/hr)***
0-530	Conglomerate +limestone + shale +bit of anhydrite+ dolomite	**1.65**	26	2-15	120	499	64.75	7.71
530-624	Dolomite + anhydrite	**1.765**	17.5	10	100	94	28.5	3.30
624-674	Mostly dolomite + anhydrite	**1.825**	17.5	12	120	50	7.25	6.90
674-830	Dolomite + bit of anhydrite	**1.781**	17.5	12	120	156	44.75	3.49
830-1082	Dolomite + anhydrite	**1.755**	17.5	16	120	252	44.75	5.63
1082-1287	Dolomite + shale+marl	**2.15**	17.5	18	120	205	50	4.10
1287-1454	Marl + limestone	**1.765**	17.5	15-18	120	167	52.25	3.20
1454-1538	Dolomite+ bit of marl	**1.95**	17.5	15-18	120	84	46.5	1.81
1538-1639	Dolomite+ bit of marl	**1.95**	17.5	15-18	120	101	40.5	2.49
1639-1706	Light limestone+ bit of marl	**1.85**	17.5	15-18	120	67	43.5	1.54
1706-1773	Light limestone	**1.079**	17.5	15-18	120	67	33	2.03
1773-1929	Shale + limestone	**1.764**	17.5	15-18	120	156	46.75	3.34
1929-1951	Shale +bit of limestone	**2.10**	17.5	15	100	22	8.5	2.59
1951-2009	Limestone + bit of shale	**1.35**	12.25	15	100	60	15.25	3.93
2009-2022	Shale + bit of limestone	**2.1**	12.25	18	100	13	1.75	7.43

5. RESULTS and DISCUSSION

The specific energy obtained from applying Rabia's equation i.e. eq. (3) is plotted versus depth along with the actual qualitative bit tooth wear (dimensionless units). Simultaneously, the specific energy produced from the new developed formula in this work (Equation 7) is compared to the *in-situ* bit tooth wear for three deep wells at Nasriya field at various drilled formation intervals. The obtained graphs show that the new developed formula exhibits a good agreement trend with actual bit tooth wear. The use of the new formula is limited as a trending tool for monitoring the wear of the drill bit tooth.

The calculations are done through applying Equations (3) and (7) after using homogeneous units.It is worth noting that, the specific energy resulted from applying the new suggested formula shows overestimated values compared with the values of the specific energy obtained from applying Rabia's equation, therefore, it is recommended when applying the new formula, it should be used as a trending tool for invigilating the bit tooth dullness.

Figure (6) illustrates the specific energies obtained fromRabia's equation and from the new formula against depth for well Nasriya #1 compared with the qualitative bit tooth wear. The specific energies produced from Rabia's and the new suggested technique show a good agreement at most depths. However, the new technique shows more sensitivity towards the high wear of the bit inserts especially at hard formations such as sandstone. This is clearly shown at depths from 2660 to 3010 m as the new suggested formula exhibits extreme high values of specific energy at this depth range due to the existence of sandstone formations as provided from the lithology of the offset adjacent wells.

It is worthy to clarify that, the path of the new specific energy shows similar peaks compared to the actual bit tooth wear, whereas Rabia's formula shows also a good agreement, but with less sensitivity towards the intervals of high tooth wear. At shallow depths, both techniques of the specific energy demonstrate a good matching with the qualitative bit tooth dullness, except the fact that the new suggested technique shows sharp more peaks than Rabia's.

The analysis of well Nasriya #2, shows that at a depth range of 2400-3190 m, the specific energy obtained from the new developed method shows extreme high values compared with Rabia's. This is attributed to the presence of rock formations that have high hardness. From the lithology of the adjacent wells to well Nasriya #2, it is shown that sandstone formation is dominant.

At depths before 2000 m, the specific energies of the two used methods show a similar trend with the *in-situ* bit tooth wear.

For well Nasriya #3, the data collected from the bit record were available from depth 1978 m and beyond, while before this depth, the qualitative bit tooth wear was missing, therefore, the calculations for this well will be limited at depth 1978 m and beyond.

From depth 1978 to 2775 m, both specific energies of Rabia and the new one show a good matching with the bit tooth dullness. Depths between 2775 and 3308 m, Rabia's and the new developed formula show an acceptable agreement with the bit tooth wear. However, the new technique exhibits an overestimation. This overdo is attributed to rock of high hardness such as sandstones and compact shale.

At depth 3364 m till the end of the well, the specific energy resulted from Rabia's equation shows a disagreement with the trend of the actual bit tooth wear, whereas the new developed method exhibits a good agreement.

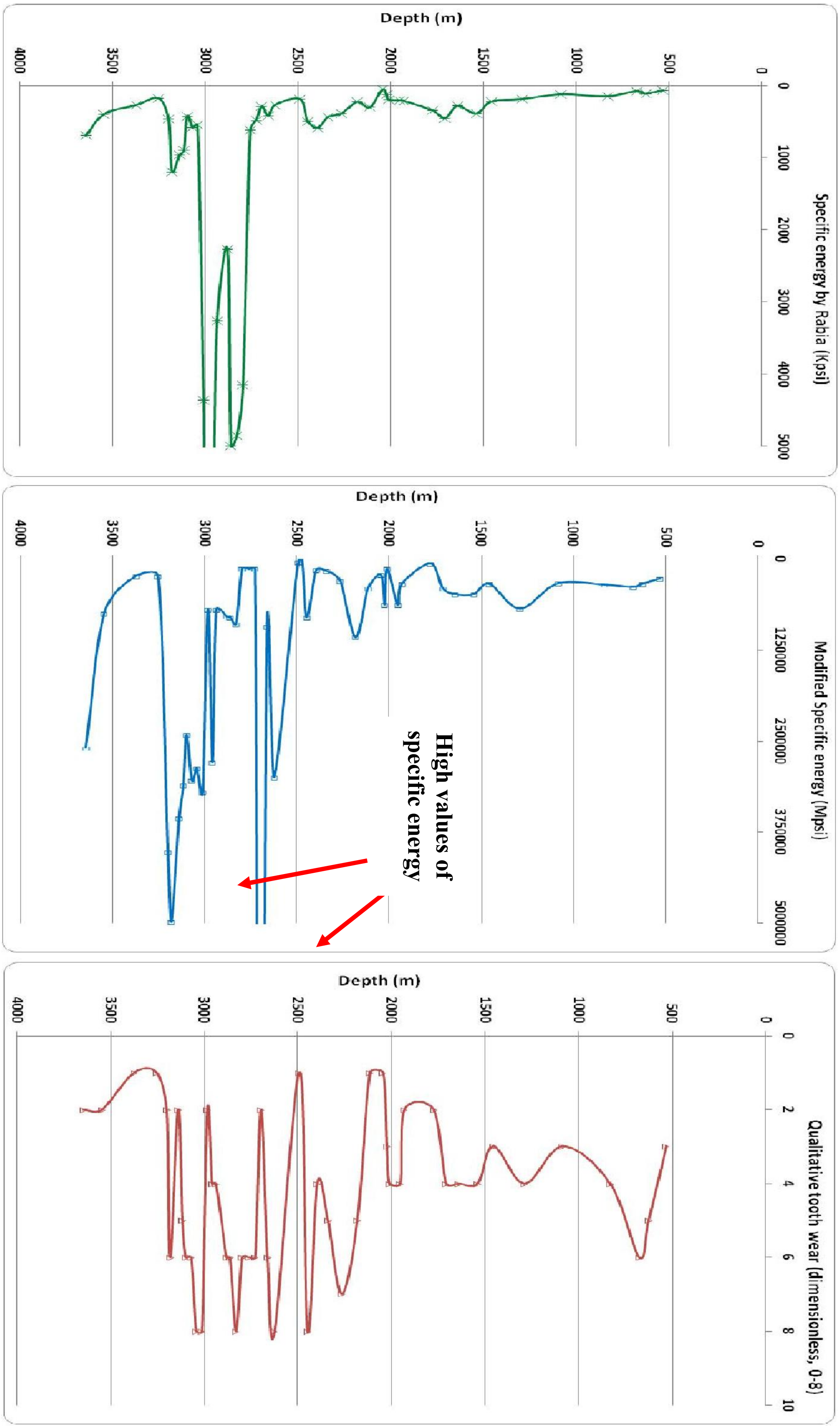

Fig. (6) Specific energies of Rabia and new formula and the actual bit tooth wear versus depth for well Nasriya #1

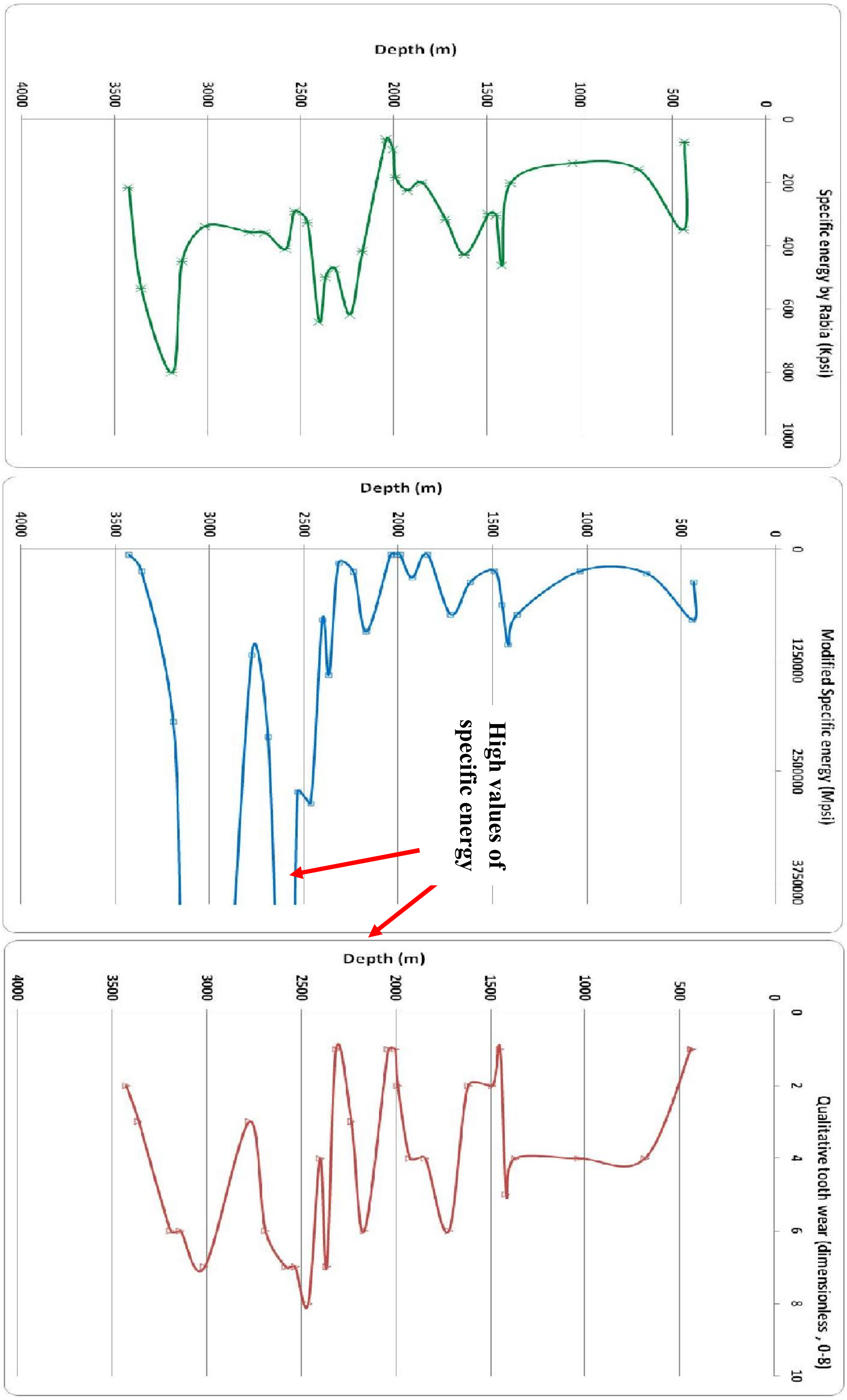

Fig. (7) Bit tooth dullness compared to the specific energies of Rabia and new formula versus depth for well Nasriya #2

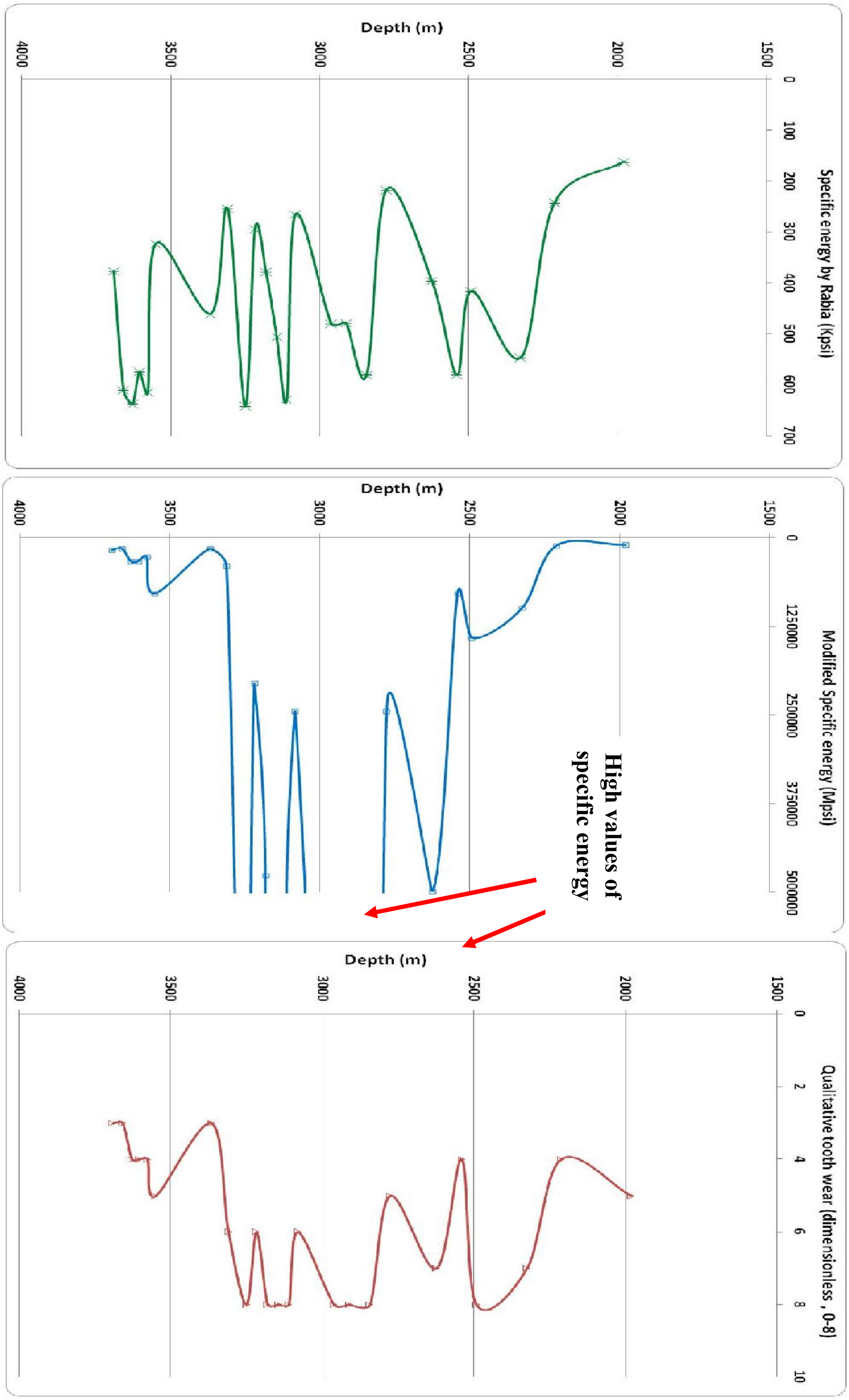

Fig. (8) Comparison of specific energies of Rabia and new formula with the qualitative bit tooth wearversus depth for well Nasriya #3

6. CONCLUSIONS

1- The new approach is based on three body abrasion, where the ratio of hardness of the rock over that of the bit has a great effect on the determination of the bit wear.
2- The values of the specific energy obtained from the new developed formula are overestimated compared with the values of the specific energy produced from Rabia, therefore, this technique is limited for the purpose of monitoring the wear of the drill bit wear as a trending tool only.
3- At shallow depths, the lithology is complicated, therefore it is quite complex to determine the pure lithology at these shallow depths and consequently affects the determination of the specific energy.
4- At rock formations that have high hardness, the specific energy resulted from the new suggested formula demonstrates extremely high values, especially at sandstone formations as shown at depths between 2660 and3180 m.
5- This technique could be used as an assisting tool for the surveillance of the bit tooth dullness while drilling.

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REFERENCES

Available from: http://www.dtj-online.com/userfiles/file/Vol70Num625_31-34.pdf

Bhushan, B. 2000. Modern Tribology Handbook. CRC Press, Florida. USA.

Chen, X., Fan, H. , Guo, B., Gao , D., Wei, H. and Ye ,Z. . 2014. Real-Time Prediction and Optimization of Drilling Performance Based on a New Mechanical Specific Energy Model. Arab Journal for Science and Engineering. **39**(11), PP. 8221-8231.

Dupriest, F. E. and Koederitz, W. L. 2005. Maximizing Drill Rates with Real-Time Surveillance of Mechanical Specific Energy. In: The SPE/IADC Drilling Conference, 23-25 February 2005, Amsterdam. The Netherlands.

Farrelly, M. and Rabia, H. 1987. Bit Performance and Selection: A Novel Approach. In: The IADC/ SPE Drilling Conference, 15-18 March 1987, New Orleans, Louisiana. USA.

Gates, J.D. 1998. Two-body and three-body abrasion: A critical discussion, Wear, **214**(1), PP. 139-146.

Gokhale, B. V. 2010. Rotary drilling and blasting in large surface mines. Kent: CRC Press.

Gonzalez, J., Quintero, F., Márquez, R., Rosales, S., and Quercia, G. 2011. Formulation Effects on the Lubricity of O/W Emulsions Used as Oil Well Working Fluids In:Biresaw, G., and Mittal, K. eds. Surfactants in Tribology, Volume 2: CRC press, PP. 241-265.

Imhoff , C.H., Brown, D.R., Hane, G.J., Hutcinson, R.A., Erickson, R., Merriman, T., Gruber, T., and Barber, S. 1985. A Review of Tribological Sinks in Six Major Industries, Technical Report PNL-5535, Pacific Northwest Laboratory, Richland, WA.

JGS, LLC. 2014. Mechanisms of wear, 2014. [Online]. [Accessed 13 August 2016]. Available from:http://www.jgs-nitriding.com/index.php/2014-09-09-14-47-03/methods-of-surface-failure

Mouritz, A. P. and Hutchings, I. M. 1991. The Abrasive Wear of Rock Drill Bit Materials. Society of Petroleum Engineers.

Nguyen, T. and Van, Q. 1995. Insert attack angle for roller cone rock bits. EP0452058 B1. 1995-10-25.

Osipov, A. S., Bondarenko, N.A. , Petrusha, I. A. and Mechnik, V.A. 2010. Drill bits with thermostable PDC inserts. Diamond tooling journal. [Online].**70**(625), PP. 31-34. [Accessed 16 September 2015].

Pessier, R. C. and Fear, M. J. 1992. Quantifying Common Drilling Problems With Mechanical Specific Energy and a Bit-Specific Coefficient of Sliding Friction. In: The SPE Annual Technical Conference and Exhibition, 4-7 October 1992, Washington, D.C. USA.

Rabia, H. 1985. Specific Energy as a Criterion for Bit Selection. SPE Journal of Petroleum Technology. **37**(7), PP.1225-1229.

Rabia, H., Farrelly, M., and Barr, M. V. (1986. A New Approach to Drill Bit Selection In: The SPE European Petroleum Conference, 20-22 Oct. 1986, London, UK.

Rabinowicz, E. 1977. Abrasive Wear Resistance as a Material Test. Lubrication Engineering. **33**(7), PP. 378-381.

Reed Tool Company. 1999. Electronic Reference Guide.

Security Rock Bits Drilling Tools General Catalog, 1984-1985.

Waughman, R. J., Kenner, J. V. and Moore, R. A. 2002 .Real-Time Specific Energy Monitoring Reveals Drilling Inefficiency and Enhances the Understanding of When to Pull Worn PDC Bits. In: The IADC/SPE Drilling Conference, 26-28 February 2002, Dallas, Texas. USA.

Waughman, R. J., Kenner, J. V. and Moore, R. A. 2003. Real-Time Specific Energy Monitoring Enhances the Understanding of When To Pull Worn PDC Bits. SPE Drilling & Completion. **18**(1), PP. 59-68.

NOMENCLATURE

CPF	cost per foot ($/ft)
d	bit diameter (m)
F	applied load (N)
H_a	hardness of the abrasive body (Pa), (GPa)
H_b	hardness of the bit (Pa), (GPa)
H_R	hardness of the rock formation (Pa), (GPa)
H_w	hardness of the abraded body (Pa), (GPa)
HV	vickers hardness number
IADC	international association of drilling contractors
ISOC	iraqi south oil company
L	depth interval being drilled (m)
N	rotary speed (rpm)
PDC	polycrystalline diamond compact
PR	penetration rate (ft/hr)
SE	specific energy (psi)
TC	tungsten-carbide
V_L	linear velocity (m/sec), (m/min)
V_R	volume of the of rock removed (m^3)
V_w	volume of the material removed (m^3).
W	weight on bit (N)
X	sliding distance (m)
θ	abrasion angle (45-0°)