DIAMOND CORING BIT EFFICIENCY IN THE HEKİMHANFORMATION

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ABSTRACT. — The worn out bits, used in the core-drilling operations carried out in the Hekimhan Formation, mostly around Karakuz (in 1960), have been returned to their manufacturers. In this way it has become possible to know the amount of diamond loss and to realise the economic importance of the percentage of core recovery, the size of the diamonds, and the physical characteristics of bits, in the evaluation of their efficiency. The results have been presented in the following tables, graphs and discussions.

Best results have been obtained by the relatively cheap, average quality coring bits carrying West African bortz diamonds. More expensive and good quality coring bits with oriented diamonds did more work; but, because of the small number available, no conclusive results could be obtained.

INTRODUCTION

The 59 bits, which have been tested in the Hekimhan Formation, had a total amount of penetration of 1002.30 meters. The various rocks that have been cut through are shown below :

563.95	meters	Hematite-magnetite
147.80	»	Altered eruptives
109.55	»	Ophiolites, serpentines and other basic rocks
86.85	»	Microsyenite, porphyritic trachyte
75.40	»	Tuffs
9.50	»	Limonite
8.20	»	Limestones
1.05	»	Radiolarites
1002.30	»	**Total**

Thus, it can be stated that, the drilled Hekimhan Formation contains 56 % hematite and magnetite, 23 % altered and unaltered eruptive rocks, 11 % ophiolitic rocks, and 10 % others.

As it is apparent, the formation is composed of rocks showing variable physical characteristics. The ore-minerals (hematite-magnetite) which constitute more than half of the total, though locally very sound and massive, generally appear friable and fractured, because of the interbedded kaolinized syenites. Only 25 % of the total ore-minerals can be regarded as sound. Chemically the material consists of 70 % hematite and 30 % magnetite. There are also quartz bands which have been emplaced along the fractures within the ore-minerals, by hydrothermal solutions. In these bands, whose thickness ranges from a few centimeters to a maximum of 20 centimeters, the quartz crystals can easily be disintegrated. Fragments breaking off from the fractures, as well as the disintegrated quartz grains, because of their grinding characteristics, cause the rapid wear of the diamond matrix. Thus, with the dislocation of diamonds, the diamond loss increases.

The drilling operators, regarding this formation as a hard mass, tend to use coring bits with small diamonds. But this causes rapid abrasion of matrix by the fractured formation, consequently letting the small diamonds fall, which are slightly embedded in the matrix, in any case.

Because the formation is, at the same time, hard, care must be taken to use either coring bits with medium size diamonds or impregnated coring bits with small diamonds which continuously produce new layers of diamond grains as the outer ones become worn out. The impregnated bits are preferred to coring bits with large diamonds, which have a small amount of cutting surface, and to coring bits with small diamonds, which have a large possibility of falling off.

The altered eruptive rocks are generally kaolinized syenites and trachytes. It is a soft and easily disintegrated rock. The small amount of quartz grains within the disintegrated rock damages the bit in the same way as has been explained above.

The porphyritic microsyenites and porphyritic trachytes are fairly sound and hard rocks. The material that is harmful to the bits is again the hydrothermal quartz bands which disintegrate rapidly.

Generally no difficulties are presented to diamonds by the other rocks (basic rocks, limestones, limonites tuffs).

CHARACTERISTICS AND NUMBERS OF DIAMOND BITS

New or reset 59 bits, used in the drilling operations and made by different manufacturers, have been evaluated.

Coring bits, made by the firms of Longyear, Sprogie and Henwood, Svenska-Craelius and Van Moppes, carry West African bortz diamonds of various qualities. Among those whose matrices are made of tungsten carbide, with a hardness of 40-55' on the Rockwell C scale, only those coring bits made by Philips have oriented diamonds.

The stone size in diamond bits is shown as the number of diamond stones per carat weight (1 carat = 0.200 gram). When the stone size decreases, this figure increases, or vice versa. Two groups have been used in the experiments. The first group consists of large stones (15-25 stones per carat, the second, of small stones (40-80 stones per carat).

Two types of coring bits have been used : L-series with female threads and X-series with male threads.

In accordance with the USA standards, there are four different coring bit diameters; those being, from small to large, E, A, B, N.

Because of the insufficient number available, coring bits of E size have not been used in the experiments. In the table below, the diameters of the borehole and the core, obtained during drilling, have been shown for each coring bit size. The diameters, types and diamond sizes have also been indicated (Table I).

Table I

Diameter	Number of coring bits according to their types and stone size						Diameter of the bore hole mm.	Diameter of the core mm.
	L		X		Total			
	15—25	40—80	15—25	40—80	15—25	40—80		
E	—	—	—	—	—	—	38.1	22.2
A	8	3	3	4	11	7	49.2	28.5
B	7	5	1	8	8	13	60.3	41.2
N	4	7	3	6	7	13	76.2	53.9
Total	19	15	7	18	26	33		
	34		25		59			

The most important factor affecting the cost of the coring-bit, is the price of the diamonds. The price of the diamonds which are used varies between 7.33-11.50 dollars per carat. Other manufacturing processes, such as orientation of the diamonds, size of diamonds, putting hard metal inserts on the bit, and the construction of various types of bits, make only 1.05-1.98 dollars per carat difference. Generally this increase is 50 % more per unit cost in the L-series coring bits or small-stone bits, compared to X-series coring bits or large-stone bits, respectively.

DRILLING METHODS AND EQUIPMENT USED

1. Types of core barrels. — During drilling operations, generally, L-series double tube swivel type core barrels have been used. In certain rare cases, where drilling was carried out in formations which produce very good cores, or in reaming, single tube core barrels have also been used. The characteristics of these core barrels are shown in detail, in the diamond drilling equipment catalogue of the Longyear firm.

Briefly, the L-series double tube swivel type core barrels are composed of two co-axial tubes. To increase the core recovery, the inner tube has been so fixed that, it remains stationary during the drilling operations. In addition, in order to prevent core blocking, there is a rubber water shut-off valve present. Together with these core barrels, generally L-series diamond coring bits have been used.

A single tube core barrel consists of one tube only. These core barrels have generally been used, together with X-series diamond coring bits, in reaming operations.

Both types of core barrels have been worked with A, B and N series drill-rods.

2 Drilling methods. — The standard drilling technique has been used. Only-water was employed for the circulation. Because of the lack of necessary instruments (r.p.m. counter, hydraulic pressure gauge), the rotation speed and the pressure on bit have entirely been left to the experience and discretion of the drill operator.

3. Types of drilling machines. — The skid-mounted «Longyear pioneer» and «Longyear junior» drilling machines with an A-drill rod capacity of 225-400 meters have been employed. Both types are powered by petrol engines and use hydraulic pressure on the drill bit.

DISCUSSIONS

a. Effect of diamond size.—From the two types of coring bits which have been used in the experiments, generally those with larger diamonds, shown as 15-25 stones per carat, have produced better results. The reason for this, as it has already been explained above, is the alternation of fractured soft formations and very hard ones. Such a composition is suitable for the development of hard particles which would abrade the matrix. This, in turn, causes the dislocation of smaller diamonds, which are less embedded in the matrix relative to the larger diamonds. Only coring bits with oriented small-stone diamonds, have given good results in this formation (Table III).

b. Effect of the quality of diamonds. — Bits carrying first grade (AAA) diamonds, because of little diamond loss and relatively high meterage per bit, are generally in the leading position. However, this advantage is usually lost because

Table - II

Orientation of diamonds	*Orientation with respect to non-resistant surfaces*	*Random orientation*	*Orientation with respect to resistant surfaces*
Number of stones on bit	148	148	148
Number of stones/carat	8-12	8-12	8-12
Weight of diamond on bit (carat)	14.37	18.11	15.35
Amount of oriented resistant surfaces on bit (%)	22	36	84
Meterage per bit (m.)	19.40	24.70	30.30
Penetration rate (cm./min.)	6.9	7.7	7.8
Diamond loss per bit (carat/bit)	3.41	1.21	0.45
Diamond loss per meter (carat/m.)	0.176	0.049	0.015
Percentage of diamond still usable (%)	76	93	97

Table III - Effect of diamond size

	Number of diamond stones per carat	
	15-25	*40-80*
No. of bits in experiments	26	33
Meterage per bit (m.)	23.03	15.27
Diamond loss per meter (carat/m.)	0.442	0.593
Cost of bit per meter ($/meter)	3.92	5.41

Table IV - Effect of core recovery

	Core recovery %	*Bit types and diameters*					
		L			*X*		
		AXL	*BXL*	*NXL*	*AX*	*BX*	*NX*
Number of bits in experiments	50 +	1	4	7	1	1	2
	— 50	9	6	3	5	8	6
Meterage per bit (m.)	50 +	48.60	16.50	13. 55	57. 10	12. 75	14. 60
	— 50	26.73	16.61	17. 92	23. 00	10. 36	16. 03
Diamond loss per meter of penetration (carat/meter)	50 +	0.131	0.54	0.756	0.161	0.646	0.781
	— 50	0.251	0.57	0. 60	0.294	0.889	0. 90
Cost of bit per meter of penetration ($/meter)	50 +	1. 23	4.82	6. 70	0. 90	5. 41	6. 64
	— 50	2. 26	5.15	5. 31	2. 69	7. 66	8. 27

% 50 + Bits giving more than 50 % of core recovery.

% — 50 Bits giving less than 50 % of core recovery.

Table V - Effects of core bit types and sizes

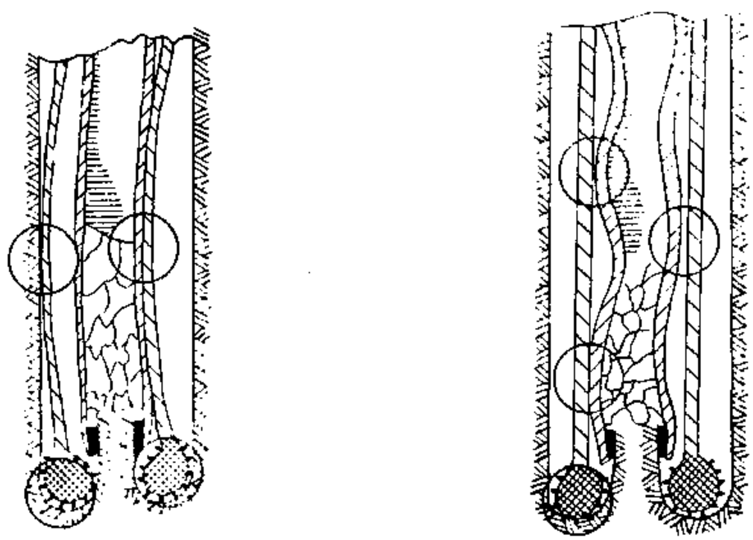
	A		*B*		*N*		*Average*	
	L	*X*	*L*	*X*	*L*	*X*	*L*	*X*
Number of bits in experiments	7	11	9	12	9	11	25	34
Meterage per bit (m.)	26.93	24.34	18.17	10.63	16.72	15.17	20.53	16.11
Core recovery (%)	30.1	32.2	43.4	26.1	58.0	25.6	40.0	28.6
Diamond loss per meter (carat/m.)	0.260	0.296	0.524	0.863	0.596	0.875	0.431	0.627
Cost of bit per meter of penetration ($/m.)	2.42	2.44	4.27	7.40	5.27	7.96	3.75	5.46

of their high costs. Only coring bits with first grade small diamond stones tend to keep their advantage. However, the insufficient number of the latter type which have been used in these experiments prevents us from arriving at a firm conclusion.

c. *Effect of core recovery.* — For the evaluations, the critical point for the core recovery has been selected as 50 %. Cores giving values more or less than this figure have been grouped and the two groups compared with each other. It appears that, with the decrease in the core recovery, the loss of diamonds and consequently the cost increases. With the aid of L-series double tube swivel type core barrels, it has become possible to reduce the costs of bits. No correlation could be found between the core recovery and meterage per bit. The results show that, the cost of the bit can only be reduced by the use of the drilling technique which will give the highest amount of core recovery.

The increase of the bit diameter is accompanied by the increase of the core recovery. The experiments show that the loss of diamonds is less in the small diameter bits than in the large diameter ones. That the large diameter bits lose more diamonds, is only natural; because of the greater number of working diamonds present. Under similar conditions, there is more diamond loss in the X-series bits than in the L-series bits. This is caused by L-series double tube swivel type core barrels, used together with L-series bits, which produce good cores. Especially in the X-series bits, the decrease of the core recovery has resulted in much diamond loss (Table IV, V; Figs. 3-11).

d. Effect of coring bit types and diameters. — Amount of penetration per bit was larger with bits of small diameter. This is due to the large diameter



a b

Fig. 1 - Damage caused by excessive pressure in diamond drilling

a) 1 - Under excessive pressure the outer tube is bent, touching the inner tube; 2 - Core breaks up; 3 - Diamonds on one side do not touch the bottom; 4 - Diamonds on the other side break up under excessive pressure. b) 1 - Inner tube becomes deformed; 2 - Core breaks up; 3 - Diamonds are fractured

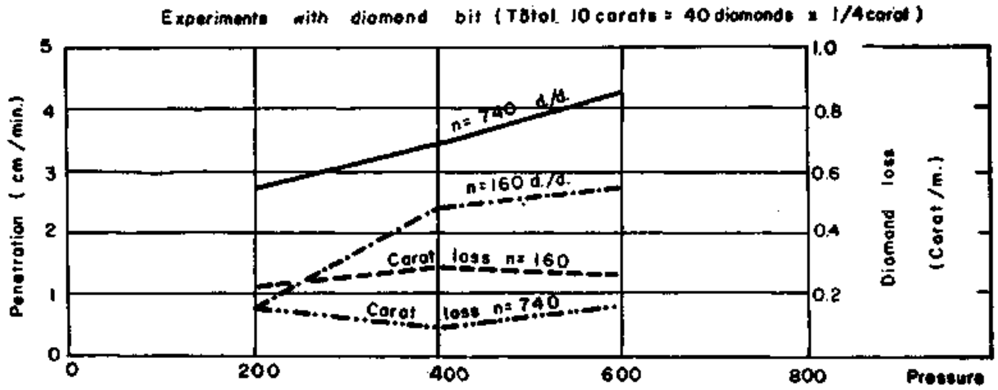


Fig. 2 - Diagram showing penetration and diamond loss under various r.p.m. and pressures
(Sunberg - Lindquist; Gottfried Prikel, Tiefbohrgeraete, page 36)

(On the diagram penetration-pressure and diamond loss-pressure have been considered separately.)

1 - Penetration at high r.p.m. increases rapidly with pressure (up to 600 kg.); 2 - At high r.p.m. loss of diamond is at minimum under 400 kg. pressure; 3 - Under low pressure (200 kg.) rate of diamond loss is the same for high and low r.p.m.; 4 - At low r.p.m. loss of diamond is at maximum under 400 kg. pressure

bits working in formations, which, being nearer to the surface, are generally softer. This causes the decrease of core recovery. Amount of meterage was high also with the L-series coring bits. The loss of diamonds per meter increases with the diameters. Generally there was a greater amount of diamond loss in the X-series bits compared with the L-series bits. The loss of diamonds in the X-series bits can be explained in three ways :

I. Reamings have generally been carried out with this type of bits. While reaming, the bit operates on soft, broken and friable surface — as a result of the previous drilling operation — rather than on firm ground.

II. Generally the X-series bits have been used with single tube core barrels. These barrels, when compared with the L-series double tube swivel type core barrels, damage the cores more and let the fragments fall to the bottom of the borehole.

These hard fragments on the floor abrade the matrix of the bit and cause the diamonds to fall out; thus increasing the diamond loss.

Care must be taken not to use diamond bits with single core barrels in formations which do not give a good core recovery.

III. Small reamings, made with single tube core barrels (therefore with X-series diamond bits), are not recorded, by negligence on the part of drilling operators, on the coring bit-record. This causes an apparent decrease in the yield of the X-series bits. The drilling operators should take into account such reaming operations.

The most important factor affecting the cost per meter is the amount of diamond loss. Therefore, small diameter bits and L-series bits cost cheaper than large diameter bits and X-series bits (Table IV, V; Figs. 3-11).

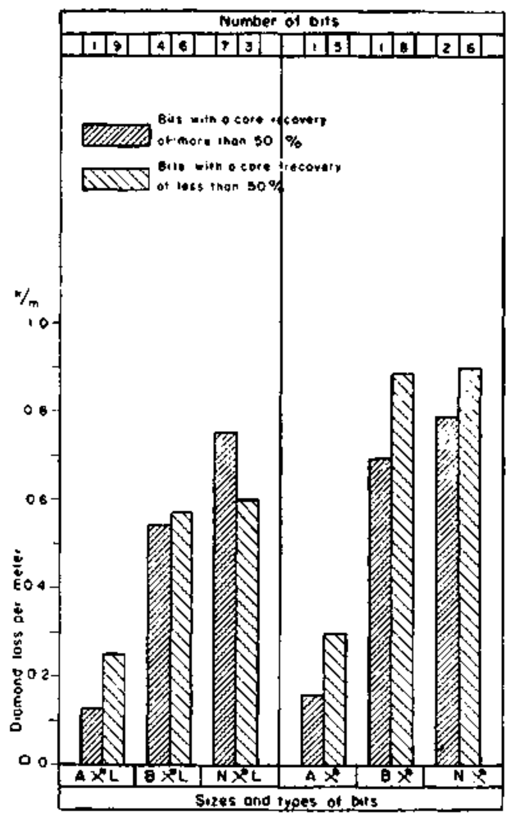


Fig. 3 - Effect of bit efficiency on diamond loss

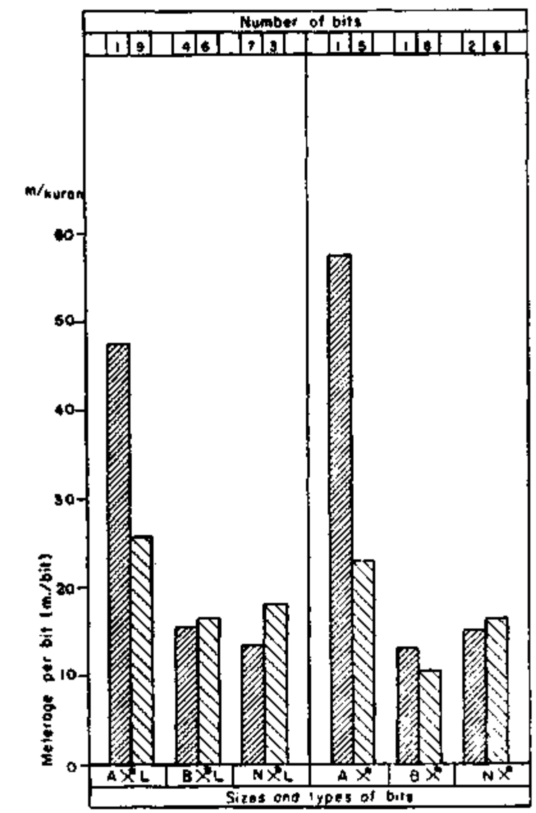


Fig. 4 - Effect of bit efficiency on amount of meterage

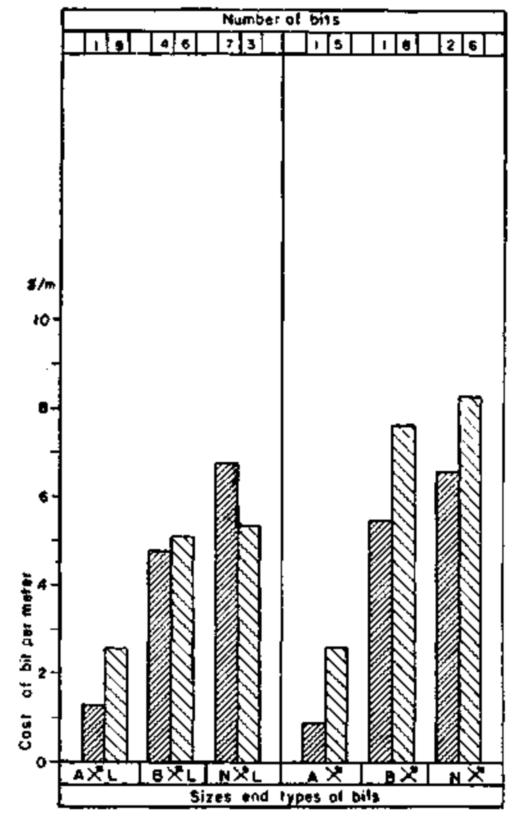


Fig. 5 - Effect of bit efficiency on cost

Conclusions: *1 - Decrease in core recovery causes increase in diamond loss; 2 - Diamond loss is high in X - series bits, because they are used with single-tube core-barrels; 3 - It is apparent that the harm due to core loss is greater in the X - series bits*

e. *Effect of the diamond matrix.* — Powder metal matrices, consisting of an alloy of Tungsten carbide and having a hardness of 40-55 on the Rockwell C scale, have been used. No important discrimination has been made on the basis of matrix. Only the lack of strengthening of the matrix in the waterways region, causes a relatively more rapid abrasion here, resulting in quick loss of diamonds. Those matrices which have been strengthened by a hard metal inserts around the waterways worked satisfactorily.

f. *Effect of waterways.* — During the drilling operation, particles that have been cut by the bit, should be swifly and efficiently passed upwards. Particles which have not been passed up in this way, stay at the bottom and cause abrasion of the matrix. The number and size of the waterways should be arranged according to the size of the diamonds and diameter of the bit. Especially on those bits, which have no hard metal inserts on side of bit but contain large diamonds, it is necessary to have long waterways in sufficient numbers.

The bits, which gave the best yield in the Hekimhan Formation, had more waterways than the others (4 on those with N size, 4 on those with B size and 2 on those with A size).

On bits with short waterways, the greatest abrasion by the fragments took place at the junction of the matrix and the bit-body. Many a time, because of this reason, a bit became useless while still having good diamonds left. Difficulty

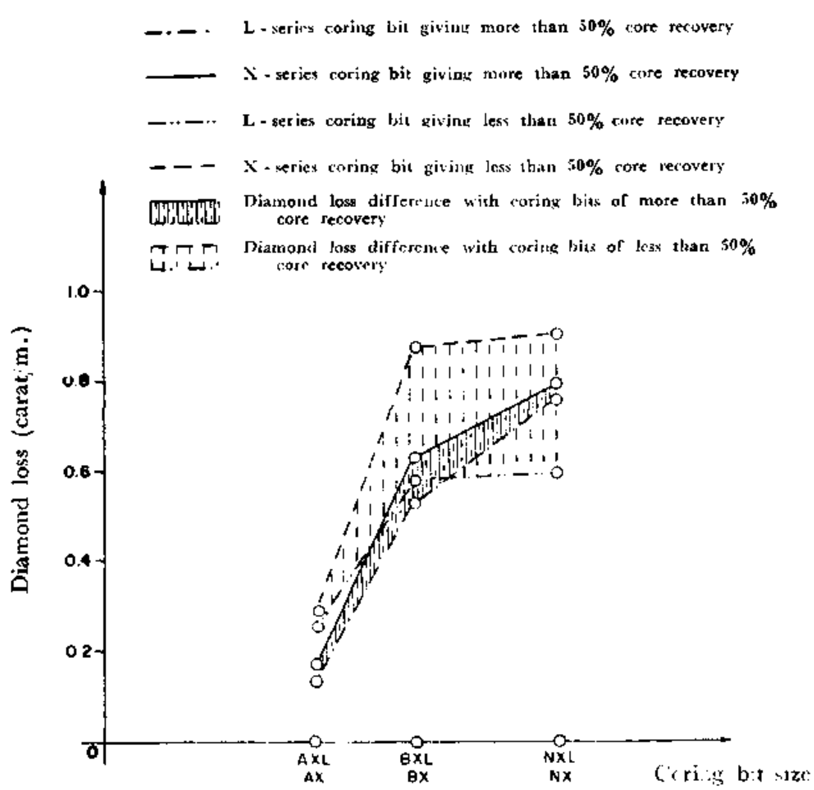


Fig. 6 - Effect of bit efficiency on diamond loss, according to diameters and types of bits

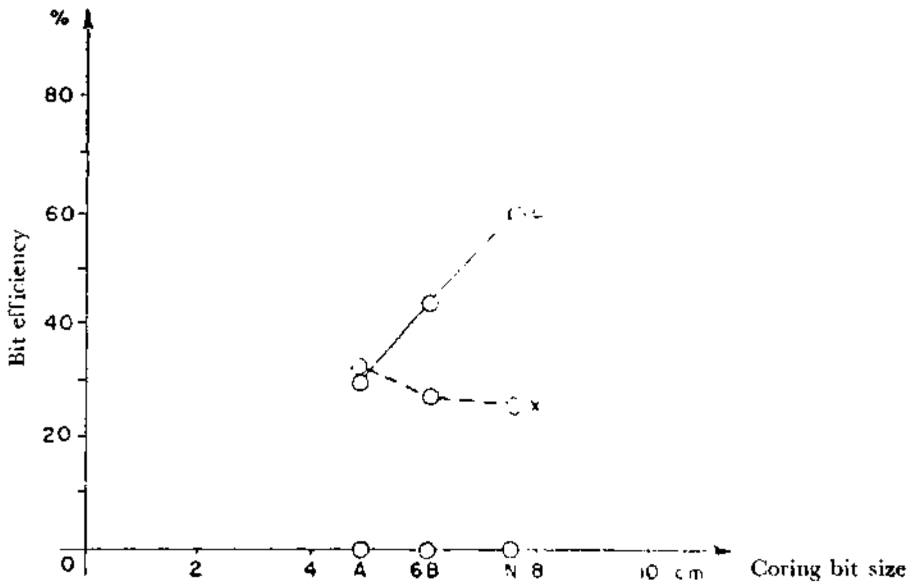


Fig. 7 - Effect of bit sizes and types on bit efficiency

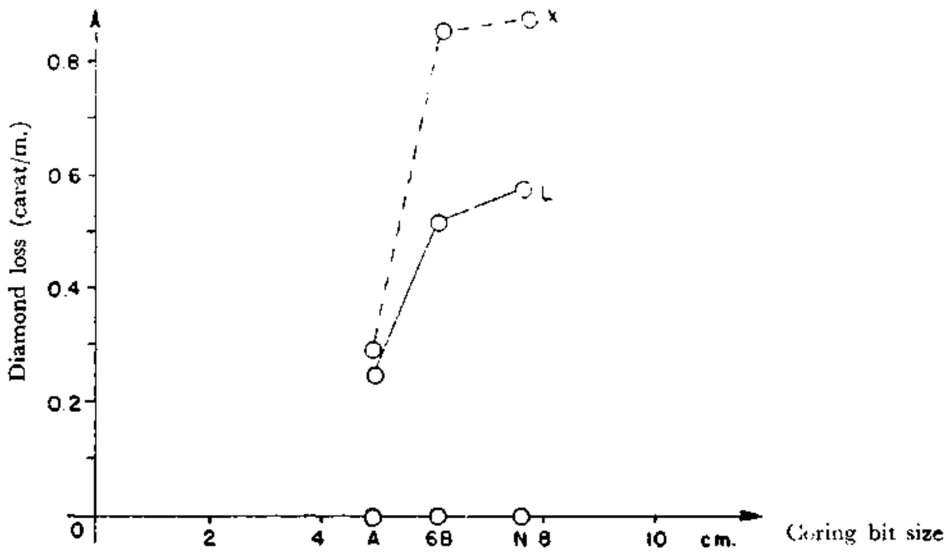


Fig. 8 - Effect of bit sizes and types of diamond loss

was experienced in fishing such bits which were stuck in the well after having broken off from the matrix.

g. Effect of the orientation of diamonds in the hard vector direction. — This is the arrangement of the diamond grains on the bit along certain directions, in ordet to reduce diamond loss and increase the amount of meterage per bit. There are two types of orientation processes :

I. The setting of cut diamonds in the matrix with their cutting faces at right angles to the direction of work. This is especially important to obtain greater bit-life, i.e. greater amount of meterage per bit.

II. Diamonds showing cleavage are set with the cleavage faces at right angles to the direction of work. This is important for the reduction of diamond loss, as well as for the increase of the amount of meterage.

A table, based on experiments (Henri Cambefort, Forages et Sondages, 1959, page 116), indicates the advantages of diamond orientation, and has been reproduced below. These experiments, using 3 bits, have been carried out in homogenous, small-grained rocks with a granitic hardness (Table. II).

A small number of bits with oriented diamonds, which have been used in drilling operations in the Hekimhan Formation, appear to be clearly superior to the other bits, as far as large amount of meterage and small amount of diamond loss is concerned. However, since the diamond orientation costs are high, in the long run this difference becomes less important. Bits with first grade oriented diamonds have an advantage of 50 % on the amount of meterage per bit, and of 40 % on the diamond loss, over the bits with haphazardly set diamonds. On the other hand, the former have a 20 % disadvantage on cost per meter of penetration, compared with the latter. This conclusion shows that a higher yield can be obtained by the orientation of cheap diamonds of relatively low quality.

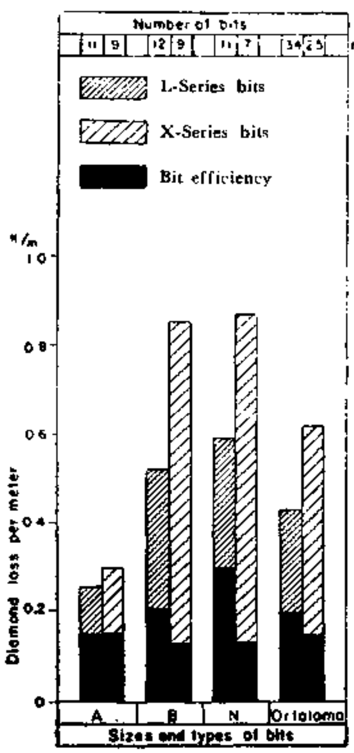


Fig. 9 - Diamond loss and bit efficiency against sizes and types of bits

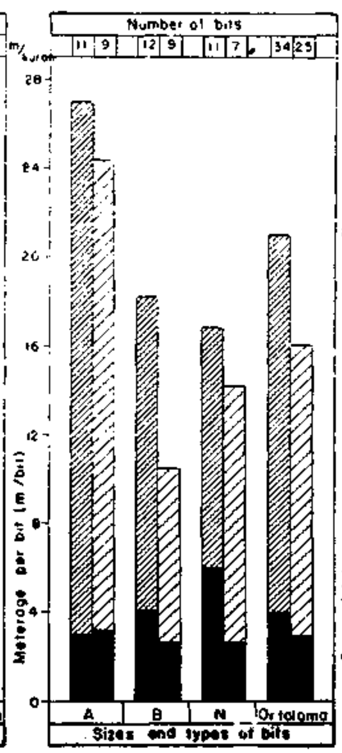


Fig. 10 - Meterage per bit (m./bit) and bit efficiency against sizes and types of bits

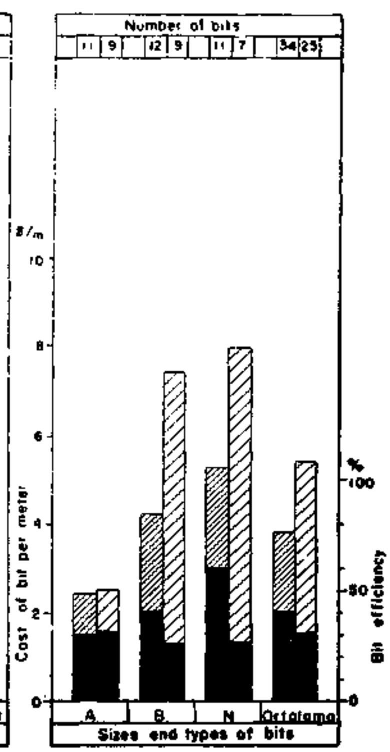


Fig. 11 - Cost of bit and bit efficiency against sizes and type of bits

h. Effect of r.p.m. and pressure on the bit during drilling, — Though highly important in the determination of the useful life of the diamonds, no records could be kept of the r.p.m. and pressures, which have to be altered according to the formation penetrated, because no suitable measuring gadgets were available. Future studies conducted on this line will have an important part in the evaluation of the diamonds.

Only some general knowledge and some observations on the r.p.m. and pressures during drilling operations will be mentioned here.

In diamond drillings rate of revolutions vary between 100-2000 r.p.m. Rarely it rises to 4000 r.p.m. Experiments show that, when working with diamond bits, the rate of revolutions must not fall below 700 r.p.m. Higher rate of revolutions gives rather better results.

The pressure (weight on bit) is generally dependent on the diameter of the bit, number of diamonds, type of formation penetrated, rate of circulation, and also on the r.p.m. Excessive pressure, apart from the damages shown in the figures below, causes the deflection of the well and jamming of the tools (Figs. 1, 2).

Each diamond can stand pressure only up to a critical value. Penetration rate increases in proportion with pressure up to this value; then, even when the pressure is kept at this critical value, the penetration rate falls. At the critical point the diamond loses its cutting ability, which is generally referred to as the «polishing of the diamond». The penetration efficiency of a polished diamond is low in the subsequent operations.

i. Effect of drill-rods. — Always A, B and N types of drill-rods have been used in the drilling operations. The later-manufactured W-series drill-rods have an increase of 10 % on the outer diameter, 15 % on the inner diameter and about 12 % on weight, compared with the A, B and N series drill-rods. The increase of the outer diameter has resulted in the reduction of the distance between casing, or well wall, and drill-rods. This causes a higher rate of water circulation which, in turn, helps to prevent the abrasion of the matrix by removing the cuttings quickly. The enlargement of the diameter and increase of weight, has also helped to damp down the vibrations which are harmful to the diamonds.

As a result we can state that the use of W-series drill-rods have proved to be useful for lengthening the life of the diamonds and diamond coring bits.

CONCLUSIONS

The following conclusions have-been drived from the information obtained in the diamond drilling operations in the Hekimhan Formation :

1. Cost per meter for the large-stone coring bits is lower than that for the small-stone ones.

2. The reduction in core recovery always leads to excessive diamond loss (especially in X-series bits).

3. Considering core recovery, meterage, loss of diamonds and cost of bits, L-series bits are more advantageous than the X-series.

4. With the increase of bit diameter, there is a proportional increase in the cost of bit per meter of penetration and in the amount of diamond loss.

5. Bits with oriented diamonds are more economical.

6. The use of L-series double tube swivel type core barrels raises the efficiency of core recovery, thus lengthening the useful life of the diamonds.

7. Though it is advantageous to have high quality diamond stones for higher meterage per bit and less amount of diamond loss, the same cannot be said for the eventual cost.

8. No discrimination could be made on basis of matrices. Only a high rate of abrasion has been noticed on bits with short waterways which had not been strengthened by hard metal inserts.

9. The selection of the proper length and number of waterways helps in the reduction of diamond loss.

10. No conclusive remarks can be made on the r.p.m.-pressure combinations during drilling operations. Future studies m this line will prove to be helpful in reducing the diamond costs.

11. Use of W-series drill rods increases the useful life of the diamonds.

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