Economics of Diamond Drilling with Conventional Rotary and Downhole Motors

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DIAMOND BIT CHARACTERISTICS

The diamond drill bit is a one-piece cutting tool, manufactured through powder metallurgy techniques, which utilizes a large number of diamonds as cutting elements. Continual improvement through design, research and developmental work has resulted in a variety of standardized bit designs to meet specific well and rig requirements. These standardized bits have been performance proven throughout the world. Design modifications, however, can be made conveniently on these tested models if unusual drilling conditions warrant it.

REASONS FOR USING DIAMOND BITS

The reason for using diamond bits is to drill less expensive and safer wells. The absence of bearings and other moving parts in diamond bits usually permits a bit life several times, or many times longer than that of conventional roller bits, and longer life eliminates one or more round trips through a given drilling interval. Also, the improvement in life increases rotating time on bottom and improves daily footage, thereby reducing drilling costs. Indirect savings are also achieved in diamond drilling by reducing the risk of gas kicks and lost circulation problems on round trips. Both of these risks can be expensive in terms of rig time and mud materials. Not to be overlooked are indirect savings accumulated by eliminating rig wear-and-tear caused by extra round trips to change roller bits.

Diamond bits usually involve a greater initial investment than rock bits, and the actual or instantaneous penetration rates achieved in some formations may be less than those for rock bits. Therefore, in order to evaluate the economics of diamond bits versus rock bits, it is necessary to compare the overall cost-per-foot of each drilling method by taking into account the total rig time involved and the overall bit cost. As would be expected, the hourly rig operating cost has a vital influence on diamond drilling economics. On small, low-cost land rigs (under $50 per hour) the net cost of one diamond bit equals the expense of many round trips, whereas on high-cost, offshore rigs, (up to $1200 per hour) as little as a two-hour saving on rig time can offset the cost of a diamond bit. It must be remembered in calculating the diamond bit cost that an average of 50 per cent of the original bit price, consisting of diamond content plus setting charge, will normally be recovered when the bit is returned for salvage cut-out.

THE BREAK-EVEN CURVE

Diamond bits should be run when their estimated performance will result in an overall cost-per-foot less than that for rock bits. In order to determine this, calculations can be made in various ways, for example, utilizing the following proven procedures (Figs. 1, 2, and 3). A theoretical break-even curve for rock bits is determined from the calculations.

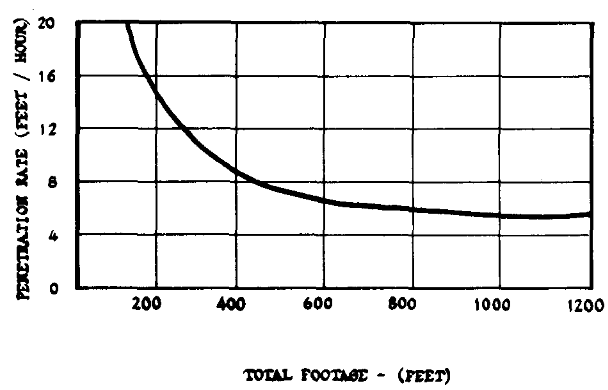

FIGURE 1

Bit performance in a general area must be known in advance in order to select effectively an appropriate diamond bit style and to predict performance; this information may be available from diamond bit records, from roller bit records or from roller bit records in the area. Otherwise, performance estimates must be based on drilling operations in similar areas and then modified in consideration of local conditions (formations harder or softer, mud heavier or lighter, hole deeper or shallower, etc.). When calculating the break-even curve for downhole motor drilling, the rental of the downhole motor is added to the rig cost per hour. True rig operating costs include the hourly equivalent rates for support costs such as camps, aircraft, boats, and special vehicles, in addition to basic rig running and rental costs.

Figure 1 shows an example of the break-even curve that is used to compare predicted diamond bit performance to predicted roller bit performance. In the break-even graph, based on calculations illustrated in Figs. 2 and 3, plot bit life in feet against drilling rate in feet per hour. Because the bit performance determines drilling economics, it is justifiable to say that a bit life versus drilling rate graph shows the economic arguments clearly and gives a break-even analysis. If the expected diamond bit performance lies above the curve, a net customer savings is indicated; if below, a loss.

If a diamond bit performance lying well on the profitable side of the curve is predicted, the bit should be run without hesitation. If the expected run is marginal or even shows a slight predicted loss, other factors such as hole conditions, mud costs and rig wear, should be taken into consideration as these indirect savings may themselves justify diamond drilling.

Break-even curves based upon rock bit runs in offset wells or rock bits run in the same formation preceding the diamond bit should be calculated and plotted in advance of running a diamond bit. After starting the bit and determining the best operating parameters, it will be possible to predict whether the penetration rate is sufficiently rapid for the bit to make money or to break-even with the expected bit life or before drilling the entire interval. If the curve indicates that the bit cannot possibly break-even, and if a faster penetration rate cannot be achieved, the bit should be pulled before appreciable diamond wear occurs or excessive rig time is consumed. In this manner losses from underperforming diamond bit runs may be held to a minimum.

After pulling a diamond bit the cost-per-foot should be calculated to determine the net gain or loss, as compared to drilling with rock bits. Either the estimated or actual net diamond consumption may be used. In most cases an approximation will suffice to indicate whether the bit run was an economic success or failure.

Even the best predictions are not infallible and it is inevitable that some bits will lose money. The final verdict as to the profitability of diamond drilling must be judged from the results obtained over an entire well or series of wells. Spectacular savings in excess of $100,000 for a single bit run are frequently obtained and these have over the years more than compensated for occasional failures or mediocre results.

DOWNHOLE MOTORS AND DIAMOND BITS

Diamond bits are a natural with downhole motors because, having no moving parts they can withstand the high rpm for long periods of time. The use of diamond bits and downhole motors for side-tracking and directional drilling has proven very economical.

This combination in conjunction with a bent sub or bent housing on the downhole motor has become almost a standard procedure for side-tracking. The advantage of this technique is that a full-gauge hole can be made while side-tracking off the plug. Therefore, the side-track operation can be completed in one trip.

Downhole motors and diamond bits are also economical in many straight-hole drilling situations. Examples of these are:

1. Faster drilling rates in some formations
2. When high torque is a problem with conventional rotary due to bad hole conditions
3. Bad cement job or hole in pipe precludes turning drill string with conventional rotary
4. Necessity to run light weight to drop or hold angle

Figures 4 and 5 show the computations and resultant break-even curve for a diamond bit and downhole motor.

DRILLING COST-PER-FOOT EQUATION

Despite the availability and simplicity of short-cut drilling cost calculation procedures (including nomograph, slide rules, conventional graphs, etc.) the reader may want to make his own calculations. Those familiar with the use of the engineering slide rule will probably find this method faster than the so-called "short-cut" methods.

The basic cost equation for rotary drilling situations is the same for roller bit and diamond bit drilling:

$$C = \frac{O}{R} + \frac{(B+TO+M)}{F}$$

where:

C = Total drilling cost per foot, (\$/ft.)
O = True rig operating cost, including indirect cost of camps, support, etc., (\$/hr.)
R = Rate of penetration, (ft./hr.)
F = Bit life, (feet)
B = Net bit cost, (\$)
T = Round trip and circulating time at this depth, (hours)
M = Mud conditioning and added costs incurred on each trip, (\$)

When values for drilling variables, with units as indicated at the right, are substituted into this formula, the value of C, drilling cost, can be determined and the answer will be in units of dollars per foot.

The same basic drilling cost formula can be expressed in another way which may be easier for some to use.

$$\frac{\left(\begin{matrix}\text{DRLG}\\ \text{TIME}\end{matrix} + \begin{matrix}\text{TRIP}\\ \text{TIME}\end{matrix}\right)\left(\begin{matrix}\text{RIG}\\ \text{COST}\end{matrix} + \begin{matrix}\text{SUPPORT}\\ \text{COST}\end{matrix}\right) + \left(\begin{matrix}\text{NET BIT}\\ \text{COST}\end{matrix}\right)}{\text{BIT FOOTAGE}}$$

The drilling time and rotating time must be in units of hours; rig and support costs must be in units of dollars per hour (not dollars per day); net bit cost in dollars and bit footage, obviously, in feet.

SUMMARY

There are, then, various benefits in running diamond drilling bits. These benefits are tied directly or indirectly to economics—money.

1. Drill cheaper
   a. faster drilling rates in many formations
   b. more footage per trip
   c. fewer trips and less mud cost
   d. ream out and stay out to gauge
   e. less fill; reduce washing down time
   f. easier on rig parts and maintenance
2. Drill safer
   a. fewer trips reduce chance of gas kicks, gas cutting of mud
   b. easier on crew
   c. no bit parts in hole; worn out bit is still in one piece
   d. wide-open junk slots reduce chance of pipe tripping pressure surges

BIBLIOGRAPHY

Christensen Diamond Products Co., *Diamond Drilling Handbook,* Second Edition, April, 1970.

PREDICTION OF DIAMOND BIT DRILLING COSTS

Prepared for Mr. Drilling Superintendent

STATE Oilwell

COMPANY Deep Well Oil Company WELL Toughrock #1 COUNTRY Hardrock

FORMATION NAME Pennsylvanian TYPE ROCK sand & shale

RECOMMENDED Diamond Bit Size and Style MD-41

ESTIMATED DIAMOND Bit Performance: Footage 927 (G) Penetration rate 2.4 (H)

(I) Cost of drilling interval (G) with Rock Bits = ($K_1 \times G$) = 91.00 X 927 = 84,357

(II) Less cost of Diamond Drilling:

1. Rotating cost ($\frac{G}{H} \times A$) = 927/2.4 X 100 = 38,600.
2. Trip Cost (E x A) = 10 X 100 = 1,000.
3. Diamond Bit Cost (F) = 5,881.

TOTAL (1 + 2 + 3) = 45,481. = 45,481.

(III) Difference (I) Minus. (II) = Net saving with Diamond Drilling = 38,876.

ROCK BIT PERFORMANCE:

Size	Name	Type	Footage	Rotating Hours	Trip Time	Depth Out
9 1/2			41	20	10	15,256
9 1/2			74	35 1/2	10	15,330
9 1/2			58	28 1/2	10	15,338
TOTAL						

RIG COST $ 100.00 PER HR A

ROCK BIT COST $ 1481.80 EACH B

AVERAGE ROCK BIT LIFE 28 HRS C

AVERAGE ROCK BIT FOOTAGE 58 FEET D

AVERAGE TRIP TIME 10 HRS E

NET DIAMOND BIT COST (EST. 50% OF PRICE) $ 5881.00 F

1. ROCK BIT DRILLING COST–PER–FOOT:

$$= \frac{A(C+E)+B}{D} = \frac{100\ (28 + 10) + 1481.80}{58} = 91.00$$

$$= \quad 91.00 \quad K_1$$

FIGURE 2

2. RATIO OF RIG COST TO ROCK BIT COST PER FOOT:

$$= \frac{A}{K_1} = \frac{100}{91} = 1.1$$

$= \underline{\qquad\qquad 1.1 \qquad\qquad} K_2$

3. RATIO OF (TRIP TIME x RIG COST + NET DIAMOND BIT COST) TO ROCK BIT DRILLING COST:

$$= \frac{(A \times E) + F}{K_1} = \frac{(100 \times 10) + 5881.}{91} =$$

$= \underline{\qquad\qquad 76 \qquad\qquad} K_3$

4. PREPARATION OF GRAPH ILLUSTRATING MINIMUM DIAMOND BIT PERFORMANCE:

Drlg. Hours	X	K2	=	+	K_3	=	Total Footage(G)	÷	Drlg. Hours	=	Penetration Rate (H)
5	X	1.1	= 6	+	76	=	82	÷	5	=	16.4
10	X		= 11	+		=	87	÷	10	=	8.7
20	X		= 22	+		=	98	÷	20	=	4.9
30	X		= 33	+		=	109	÷	30	=	3.6
40	X		= 44	+		=	120	÷	40	=	3.0
50	X		= 55	+		=	131	÷	50	=	2.6
60	X		= 66	+		=	142	÷	60	=	2.4
70	X		= 77	+		=	153	÷	70	=	2.2
80	X		= 88	+		=	164	÷	80	=	2.1
90	X		= 99	+		=	175	÷	90	=	1.9
100	X		= 110	+		=	186	÷	100	=	1.8
130	X	1.1	=143	+	76	=	219	÷	130	=	1.7

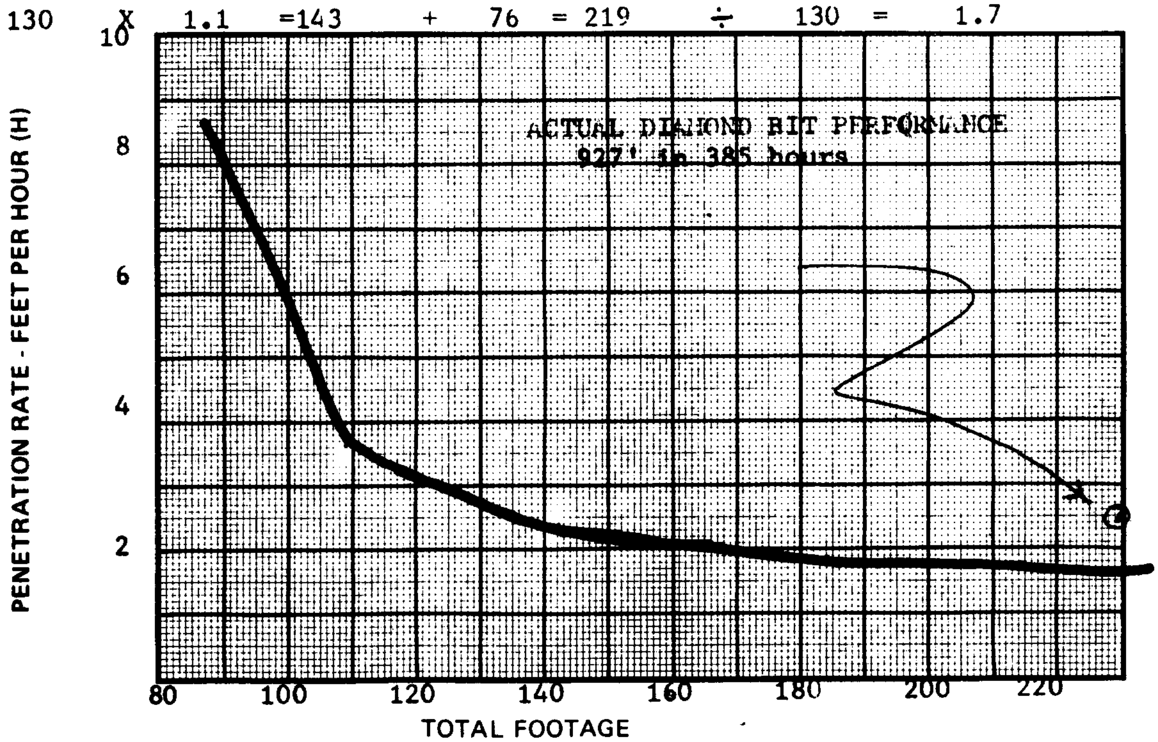

FIGURE 3

PREDICTION OF DIAMOND BIT DRILLING COSTS

Prepared for Mr. Drilling Engineer

STATE Oilwell

COMPANY Crude Oil LTD. WELL Bottleneck # COUNTRY Hardrock

FORMATION NAME Cretaceous TYPE ROCK shale

RECOMMENDED Diamond Bit Size and Style MD-33

ESTIMATED DIAMOND Bit Performance: Footage 700 (G) Penetration rate 4.9 (H)

(I) Cost of drilling interval (G) with Rock Bits = (K_1 x G) = 51 X 700 = $\boxed{35,700.}$

(II) Less cost of Diamond Drilling:

1. Rotating cost ($\frac{G}{H}$ x A) = 700/4.9 X (100 + 65 down-hole motor) = $\boxed{23,430.}$
2. Trip Cost (E x A) = 8 X 100 = $\boxed{800.}$
3. Diamond Bit Cost (F) = $\boxed{2,780.}$

TOTAL (1 + 2 + 3) = $\boxed{27,010.}$ = $\boxed{27,010.}$

(III) Difference (I) Minus. (II) = Net saving with Diamond Drilling = $\boxed{8,690.}$

ROCK BIT PERFORMANCE:

Size	Name	Type	Footage	Rotating Hours	Trip Time	Depth Out
6 1/2			172	44	8	15,095
6 1/2			58	21	8	15,154
6 1/2			233	103	8	15,387
TOTAL			463	168		

RIG COST $ 100.00 PER HR A

ROCK BIT COST $ 1470.00 EACH B

AVERAGE ROCK BIT LIFE 56 HRS C

AVERAGE ROCK BIT FOOTAGE 154 FEET D

AVERAGE TRIP TIME 8 HRS E

NET DIAMOND BIT COST (EST. 50% OF PRICE) $ 2780.00 F

1. ROCK BIT DRILLING COST–PER–FOOT:

$$= \frac{A(C+E)+B}{D} = \frac{100\ (56 + 8) + 1470.00}{154} = 7870 = 51.00$$

$$= 51.00 \quad K_1$$

FIGURE 4

2. RATIO OF RIG COST TO ROCK BIT COST PER FOOT:

$$= \frac{A}{K_1} = \frac{165}{51} = \quad \text{(includes cost of down-hole motor)}$$

= 3.2 K_2

3. RATIO OF (TRIP TIME x RIG COST + NET DIAMOND BIT COST) TO ROCK BIT DRILLING COST:

$$= \frac{(A \times E) + F}{K_1} = \frac{(100 \times 8) + 2780}{51} = \frac{3580}{51} = 70$$

= 70 K_3

4. PREPARATION OF GRAPH ILLUSTRATING MINIMUM DIAMOND BIT PERFORMANCE:

Drlg. Hours	X	K2	=		+	K_3	=	Total Footage(G)	÷	Drlg. Hours	=	Penetration Rate (H)
5	X	3.2	=	16	+	70	=	86	÷	5	=	17.2
10	X		=	32	+		=	92	÷	10	=	9.2
20	X		=	64	+		=	134	÷	20	=	6.7
30	X		=	96	+		=	166	÷	30	=	5.5
40	X		=	128	+		=	198	÷	40	=	4.9
50	X		=	162	+		=	232	÷	50	=	4.6
60	X		=	192	+		=	262	÷	60	=	4.4
70	X		=	224	+		=	294	÷	70	=	4.2
80	X		=	256	+		=	326	÷	80	=	4.1
90	X		=	288	+		=	358	÷	90	=	4
100	X	3.2	=	320	+	70	=	390	÷	100	=	3.9
200	X	3.2	=	640	+	70	=	710		200	=	3.6

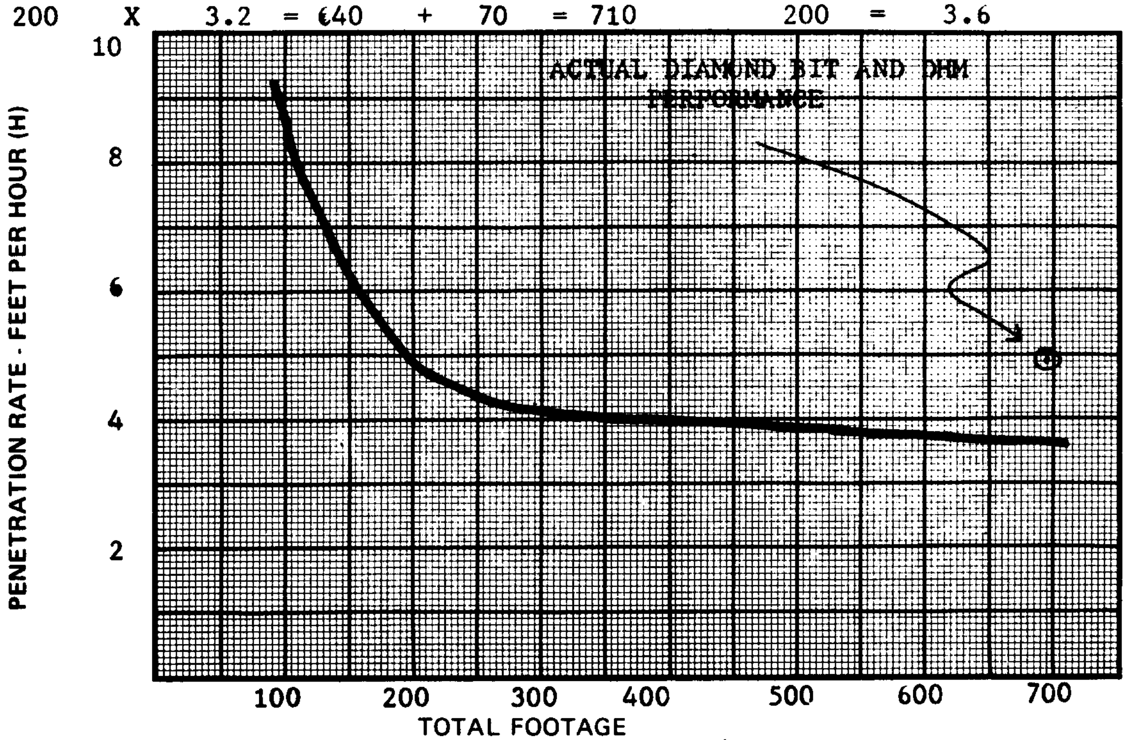

FIGURE 5