# A PRACTICAL GUIDE TO DRILLING OPTIMIZATION

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## ABSTRACT

*A procedure to optimize drilling programs is presented from a practical standpoint. The concept of a control well based on offset well data, using a cost per foot approach is discussed.*

*Once the control-well and proposed-well data have been determined, a systematic analysis of the drilling variables is carried out. This analysis is concerned with the drilling hydraulics, mud properties, bit type, bit weight, and rotary speed.*

*The final product is a well program which includes a summary of the proposed hydraulics, mud system, bit selection and operating conditions.*

*In a final analysis, proposed drilling costs are compared with costs for the control well, and the proposed cost savings is determined.*

## INTRODUCTION

Over the past two years, Amoco Computer Services has conducted several schools on the use of Amoco's Drilling Assistance Computer Programs. As a result of this experience, a simple procedure has been developed to apply the programs in the area of well planning. The purpose of this paper is to describe this procedure and discuss a typical example.

Recently, David E. Korry described the programs and showed how they were used on a deep Montana well.[1] In his paper, Korry lists the data required from the control well and the specifications for the proposed well. In addition he gives the program running procedures and how to implement the results.

The Amoco programs that will be discussed in this paper are as follows.

COST. SUM: Identifies and prices bits. Also computes cost per foot, trip time and net days for a single bit or interval.

HYD. ANAL: Computes actual hydraulic conditions at the bit for analysis of the control bit run.

HYDRAUL: Optimizes rig hydraulics, relating crossflow, and hydraulic horsepower at the bit to penetration rate of the proposed bit run.

MUDHY: Predicts effects of mud and hydraulics on penetration rate and drilling cost.

BITOP: Bit optimization program for sealed bearing and journal bearing tungsten-carbide insert bits, IADC/API series 5, 6, 7, and 8.

An attempt will be made to show how the above programs can be used to produce an optimized well plan.

## THE CONTROL WELL

The program COST. SUM is used to analyze the offset drilling data. This analysis is made to determine the most appropriate well to base optimization upon. This may result in a single control well or a composite well from several offset wells. The offset drilling data includes electric logs, bit records, mud records and mud logs.

## MUD AND HYDRAULICS

A discussion of the hydraulics programs available from Amoco has been published by B. V. Randall.[2] In this paper, Randall gives the guidelines to be followed in the analysis of the output from the computer programs.

Analysis of drilling hydraulics on offset wells is provided by the program HYD. ANAL. This program analyses the actual hydraulics of a

particular bit run. It determines existing conditions giving an exact flow rate for a given nozzle combination, drill string configuration, pump pressure, and mud properties.

Computation of optimum hydraulics for the proposed well is provided by the program HYDRAUL. This program computes the optimum balance of crossflow and jet energy to clean the bit and the hole bottom with particular mud and either conventional or tapered drill string for various average penetration rate ranges.

Effect of interaction of mud and hydraulics on penetration rate and drilling cost is provided by the program MUDHY. Data used to develop the model upon which this program is based were obtained from both full scale and microbit drilling machines with both field- and laboratory-prepared muds. The model that predicts effects of hydraulics on penetration rate was developed from data obtained from actual field results.

## BIT TYPE, WEIGHT AND ROTARY SPEED

The background of the bit optimization programs available from Amoco has been published by Jack C. Estes.[3]

The effect of bit type, bit weight, and rotary speed on penetration rate and drilling cost is provided by the program BITOP. Calculations in this program are based on extensive drilling tests where drilling responses of 7 7/8-, 8 1/2-, and 8 3/4-inch bits were determined, while bit life calculations are based on statistical analysis of field performance data.

## THE PROPOSED WELL

Specifications for the proposed well should include the maximum pump pressure and flow rate available from the mud pumps proposed for the rig. In addition, the proposed mud properties with respect to mud weight, solids content, and flow properties should be determined.

## AN EXAMPLE OF DRILLING OPTIMIZATION

The example which illustrates our optimization procedure is an Amoco Production Company well drilled in Southwestern Oklahoma and has been described in a paper by Douglas L. White.[4] The control well data is from the 1 Kelly unit drilled in 1975.

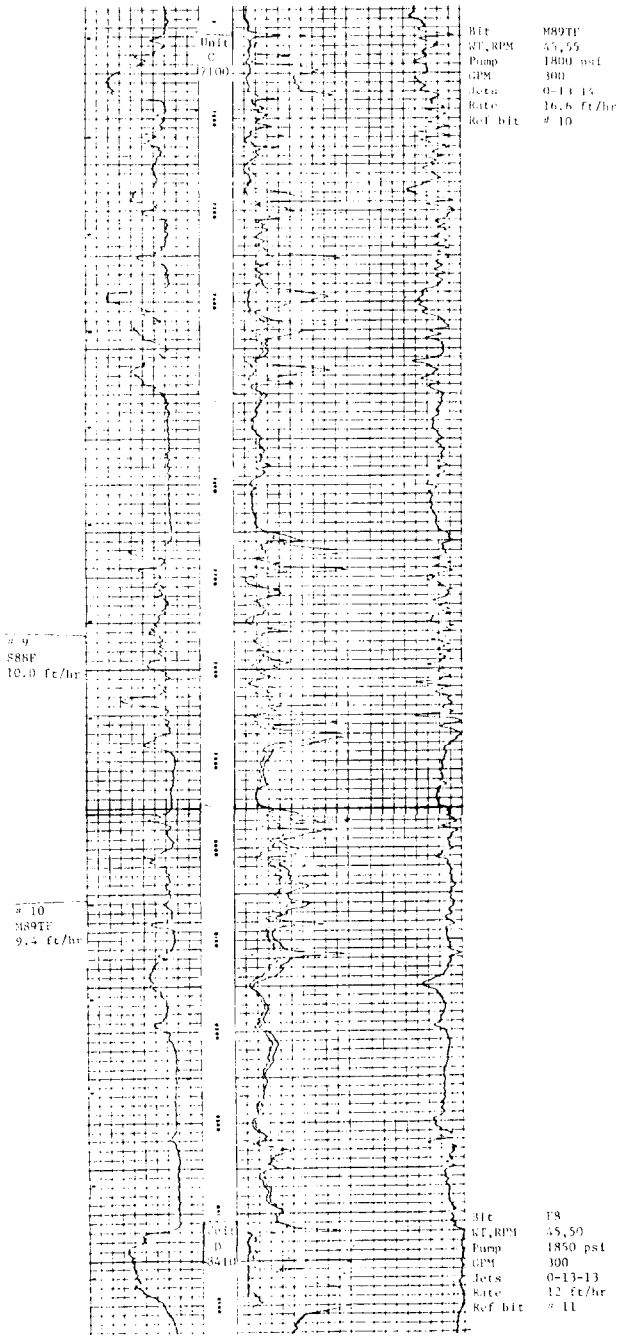


FIGURE 1 ELECTRIC LOG FOR 1 KELLY UNIT

The interval chosen to optimize was from 7100 ft to 8410 ft (Figure 1), and we would hope to drill the entire 1310 ft with one bit. A summary of the control bit run along with the proposed bit run specifications is given in Figure 2.

First the control bit run hydraulics were analyzed (Figure 3). It was found that on the control well, we

OPTIMIZATION FOR INTERVAL 7100 - 8410 FOR KELLY NO. 1

Control Bit Run:

| | |
|---|---|
| Bit Size | 7-7/8 |
| Type | M89TF |
| Depth in | 8056 |
| Depth out | 8590 |
| Footage | 534 |
| Hours | 56.75 |
| Ft/Hr | 9.4 |
| Wt. | 35 |
| RPM | 56 |
| T-B-G | 6-3-0 |
| Mud Wt. | 9.1 |
| Vis | 40 |
| PV | 7 |
| YV | 8 |
| PSI | 1500 |
| Jets | 11-11-12 |
| FPM | 335 |

Proposed Bit Run:

| | |
|---|---|
| Max Pump Pressure | 2000 PSI |
| Max GPM | 350 |
| Mud Wt. | 8.8 |
| Depth Out | 8410 |

(Can this bit drill entire 1310 foot interval?)

FIGURE 2 SUMMARY OF CONTROL AND PROPOSED BIT RUNS

had a hydraulic horsepower per square inch of bottom hole area ratio (HP/SQ IN) of 2.4, and a percentage of available pump pressure across the bit jet nozzles (%BIT) of 48 percent, both low using Randall's guidelines.[2] Next the program HYDRAUL was run (Figure 4) to determine the proposed hydraulics. From our proposed rig specification, we used a maximum pump pressure of 2000 psi and a maximum flow rate of 350 gpm. The program suggested a pump pressure of 1950 psi and a flow rate of 310 gpm. It further recommended jet sizes of 13/32, 14/32, and a blank. The HP/SQ IN ratio was thus raised from 2.4 to 3.8 and the percentage across the bit was raised from 48 to 52 percent. Using these proposed hydraulics and introducing the improved mud system (lower mud weight and MBT), we now ran the program MUDHY. The output from this program (Figure 5) indicated that we could expect an increase in footage drilled from 534 ft to 713 ft due only to improved mud and hydraulics. The assumptions made by the program MUDHY are shown in Figure 6.

Finally, we ran the program BITOP (Figure 7) using this predicted footage of 713 ft from MUDHY as our control bit run footage and found that if we ran the same bit type with a WOB of 50,000 lb and

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OPTION?HYD.ANAL

770826

ANALYSIS OF HYDRAULICS (INPUT '0' FOR UNKNOWNS)

BIT SIZE?7.875

DRILL STRING DATA:  MINIMUM OR TOTAL?M

MUD WEIGHT?9.1

DOES MUD CONTAIN A POLYMER?Y

HOLE SIZE  7.87 DP  4.5 X 3.83 TJ 6.00 X 3.25
 600.FT OF COLLARS 6.75 X 2.25 AND    0.FT  6.75 X 2.25

MUD WT. 9.1 PV  6. YV  5.

DEPTH?8590

JETS IN 32ND'S (EG.0,13,13)?11,11,12

STANDPIPE PRESSURE, FLOW RATE?1500,335

COLLAR WEIGHT AVAILABLE FOR DRILLING   41. THOUSAND POUNDS

REAL  ANNULUS  CHIP            JET  JET   HP/   %  PUMP
GPM      VEL.  RATE    JETS    VEL.  HP  SQIN  BIT HP    ECD

 276.  162.TT  130   11 11 12  299  117  2.4   48  284   9.6

CHANGE:  HOLE, BHA, MUD, DEPTH, PSI, JETS, OR STOP?S
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FIGURE 3 ANALYSIS OF CONTROL BIT HYDRAULICS

```
OPTION?HYDRAUL

770912

HYDRAULICS OPTIMIZATION (INPUT '0' FOR UNKNOWNS)

BIT SIZE, MAXIMUM PUMP PRESSURE,MAX FLOW RATE?7.875,2000,350

DRILL STRING DATA: MIN/TOTAL?M

MUD WEIGHT?8.8

DOES MUD CONTAIN A POLYMER?Y

HOLE SIZE  7.87 DP  4.5 X 3.83 TJ 6.00 X 3.25
 600.FT OF COLLARS 6.75 X 2.25 AND    0.FT  6.75 X 2.25

MUD WT.  8.8 PV  4. YV  3.

DEPTH, FT./HR.(EST)?8590,10

   84.PSI TO START CIRC.(PIPE ROTATING)    9.4#/GAL.ECD AT 310.GPM

PRESSURE 1950.

COLLAR WEIGHT AVAILABLE FOR DRILLING   40. THOUSAND POUNDS

REAL  ANNULUS  CHIP    REC.     JET   HP/   %  PUMP
GPM      VEL.  RATE    JETS     VEL.  SQIN  BIT MECH HP
 290.  170.TT  136    0 13 13  359   3.8   56  388
 300.  176.TT  143    0 13 13  371   3.9   56  401

 310.  182.TT  150    0 13 14  355   3.8   52  414 RECOMMENDED

 320.  188.TT  157    0 14 14  341   3.7   49  428
 330.  194.TT  163    0 14 15  328   3.5   45  441

RECOMMEND 1950.PSI. WITH  0 13 14 JETS FOR   3.8 HHP/SQIN

WITHOUT A FRACTURE DIVERTING BALL IN THE BIT THE PRESSURE, AT THE
SAME PUMP SPEED WILL BE ABOUT 1400. PSI WITH 13 14 14 JETS OPEN.

CHANGE: HOLE, BHA, MUD, DEPTH, PUMP, JETS, OR STOP?S
```

FIGURE 4 –OPTIMIZED HYDRAULICS USING THE PROGRAM HYDRAUL

```
OPTION?MUDHY
780227        (INPUT 0 FOR UNKNOWNS)
          E F F E C T   O F   M U D   A N D   H Y D R A U L I C S
                        O N   D R I L L I N G   R A T E

    CONTROL BIT RUN DATA:

SIZE, BIT COST, $/HR, TRIP TIME ?7.875,0,125,0

DEPTH, FOOTAGE, HOURS..... ?8590,534,56.75

WERE BIT BEARINGS, JOURNAL, SEALED, REG. ?J

MUD WT, MBT, OIL, CL-..... ?9.1,12,0,0

DID MUD CONTAIN A POLYMER..... ?Y

3-JETS, PUMP PRESSURE..... ?11,11,12,1500


    PROPOSED MUD AND HYDRAULICS:

SIZE, BIT COST, $/HR, TRIP TIME ?0,0,0,0

MUD WT, MBT, OIL, CL-..... ?8.8,8,0,0

WILL MUD CONTAIN A POLYMER..... ?Y

3-JETS, PUMP PSI, MAX FLOW RATE ?0,13,14,1950,350

... THIS HYDRAULICS MAY NOT BE OPTIMUM ...
```

| | CONTROL BIT RUN | PROPOSED BIT RUN |
|---|---|---|
| DEPTH | 8590 | |
| FOOTAGE | 534 | 713 |
| HOURS | 56.7 | 56.7 |
| PENETRATION RATE | 9.4 | 12.6 |
| COST PER FOOT | 18.36 | 13.76 |
| JETS, 32ND INCH ..... | 11 11 12 | 0 13 14 |
| HHP/SQIN AT BIT | 2.4 | 3.9 |
| JET VELOCITY | 299 | 361 |
| PCT. HHP AT BIT | 48 | 53 |
| ANNULAR VELOCITY | 162 | 185 |
| CALCULATED GPM | 276 | 315 |
| DIFFERENTIAL PRESSURE | 228 | 94 |

FIGURE 5—OPTIMIZATION WITH THE PROGRAM MUDHY USING HYDRAULICS FROM HYDRAUL

```
OPTION?BITOP
780510
AMOCO PRODUCTION RESEARCH - DRILLING CHARACTERISTICS OF INSERT BITS
TYPE '0' FOR UNKNOWN BIT COSTS.  DO NOT INPUT RUNS WITH OVER 100 RPM.
UNDER PROPOSED BIT RUN, 0,0 FOR WT,RPM WILL OPTIMIZE


     CONTROL BIT RUN DATA:
RIG COST($/HR), TRIP TIME ?125,

BIT SIZE, BIT COST ..... ?7.875,

BIT TYPE ..... ?M89TF

DEPTH, FOOTAGE, HOURS ... ?8590,1_713,56.75

W.O.B., RPM, T, B ..... ?35,56,6,3

     PROPOSED BIT RUN:
RIG COST ($/HR) ..... ?125

BIT SIZE, BIT COST ..... ?7.875,

BIT TYPE ..... ?M89TF

ADJUSTED DEPTH, TRIP TIME ?,

WT, RPM ..... ?,

CONTROL  BIT RUN:   SE    M89TF   IADC  6-2-7   $2301     6.6 HR. TRIP
PROPOSED BIT RUN:   SE    M89TF   IADC  6-2-7   $2301     6.6 HR. TRIP
```

| | WT | RPM | FT | HR | FT/HR | $/FT | |
|---|---|---|---|---|---|---|---|
| CONTROL: | 35000 | 56 | 713.0 | 56.7 | 12.56 | $ 14.33 | *** |
| PROPOSED: | 50000 | 65 | 1434.0 | 61.7 | 23.25 | $ 7.56 | |
| | 45000 | 65 | 1393.8 | 66.6 | 20.92 | $ 8.22 | *** |
| | 45000 | 55 | 1622.0 | 87.7 | 18.50 | $ 8.68 | |
| | 40000 | 65 | 1012.0 | 59.2 | 17.09 | $ 10.40 | *** |
| | 40000 | 55 | 1179.6 | 77.9 | 15.14 | $ 10.91 | |
| | 35000 | 65 | 1190.8 | 86.1 | 13.84 | $ 11.66 | *** |
| | 35000 | 50 | 1572.3 | 134.7 | 11.67 | $ 12.70 | |
| | 30000 | 65 | 1198.4 | 101.0 | 11.86 | $ 13.15 | *** |
| | 30000 | 45 | 1751.6 | 187.4 | 9.35 | $ 15.16 | |
| | 25000 | 70 | 796.8 | 83.2 | 9.58 | $ 16.98 | *** |

```
*** HOURS BASED ON MEDIAN BEARING LIFE.  WT-RPM CONDITIONS ON
    THIS LINE MAY CAUSE BIT'S CUTTING STRUCTURE TO FAIL BEFORE
    BEARING IN NON-UNIFORM FORMATIONS.  'CHECK LOG'

CHANGE: CONTROL, RIG, BIT, DEPTH, WT, OR STOP ?D
```

FIGURE 7—BIT OPTIMIZATION USING BITOP

```
CHANGE : JETS, MUD, BIT, CONTROL, PRINT ASSUMPTIONS, STOP?P
```

| | | |
|---|---|---|
| BIT SIZE | 7.875 | 7.875 |
| BIT COST | 1887. | 1887. |
| RIG $ PER HOUR | 125. | 125. |
| TRIP TIME | 6.6 | 6.6 |
| MUD WEIGHT | 9.1 | 8.8 |
| PLASTIC VISCOSITY | 6. | 4. |
| YIELD VALUE | 5. | 3. |
| MBT(LB.BBL) | 12. | 8. |
| PERCENT OIL | 0. | 0. |
| CHLORIDES | 0. | 0. |
| LB/BBL LOW GRAVITY SOLIDS | 51. | 32. |
| LB.BBL BARITE | 0. | 0. |
| DRILL PIPE OD. | 4.50 | 4.50 |
| DRILL PIPE ID. | 3.83 | 3.83 |
| TOOL JOINT OD. | 6.00 | 6.00 |
| TOOL JOINT ID. | 3.25 | 3.25 |
| FEET OF COLLARS | 600. | 600. |
| COLLAR OD. | 6.75 | 6.75 |
| COLLAR ID. | 2.25 | 2.25 |
| FEET OF BIG COLLARS | 0. | 0. |
| BIG COLLAR OD. | 6.75 | 6.75 |
| BIG COLLAR ID. | 2.25 | 2.25 |

```
  CHANGE : JETS, MUD, BIT, CONTROL, STOP ?S
```

FIGURE 6—MUDHY ASSUMPTIONS

```
     Bit No. 1 is the control bit.  Bit No. 2 is the proposed bit.
OPTION?COST.SUM

781211        COST SUMMARY FOR AN INTERVAL DRILLED.
                    MARCH 78 PRICES
WANT INSTRUCTIONS ?N

DO YOU HAVE A FILE SAVED ?N

BIT SIZE, RIG COST ($/HR) ?7.875,125

                  BIT  API COST   DEPTH                  TRIP
                  MFG CODE  $     OUT  FEET  HOURS FT/HR TIME  $/FT
BIT NO.?1

BIT TYPE?M89TF

DEPTH OUT,FEET,HOURS
 ?8590,534,56.75

          M89TF  SE 627 2301.  8590.  534.  56.7   9.4  6.6  19.14
BIT NO.?2

BIT TYPE?M89TF

DEPTH OUT,FEET,HOURS
 ?8534,1434,61.7

          M89TF  SE 627 2301.  8534. 1434.  61.7  23.2  6.6   7.56
BIT NO.?
```

FIGURE 8—COST SUM ANALYSIS OF THE CONTROL AND PROPOSED BIT RUNS

an RPM of 65 we should expect a run of 1434 ft for approximately the same number of hours on the bit.

## CONCLUSION

A post-well analysis of the actual results obtained with the proposed well plan should be carried out. This analysis would be a COST. SUM analysis of the actual to the proposed and to the original control well. This would be especially enlightening if additional wells are to be drilled in the area. For our example well, we see that by running the program COST. SUM (Figure 8) we have reduced the cost per foot from $19.14 to $7.56.

## REFERENCES


1. Korry, David E.: "Optimizing Deep Drilling Program," *World Oil* (Sept. 1977).
2. Randall, B. V.: "Optimum Hydraulics in the Oil Patch," *Petroleum Engineer* (Sept. 1975).
3. Estes, Jack C.: "Guidelines, for selecting rotary insert rock bits," *Petroleum Engineer* (Sept. 1974).
4. White, Douglas L.: "Putting Available Know-how to use can cut Drilling Cost," *Oil & Gas Journal* (Sept. 5, 1977).