APPLICATION OF DRILLING RESPONSE AND GAS-CUT DATA TO OPTIMIZE DRILLING

DANIEL E. BOONE
Petroleum Consultant

INTRODUCTION

Drilling optimization can be defined as the application of all the forces available in drilling to a desired depth, with a minimum total cost. If this optimum is to be approached, the drilling supervisor must have accurate data, timely interpretations and confidence in its application.

This paper will concentrate on data collection and interpretive systems as technical support to the drilling supervisor.

PRESSURE DETERMINATION

Pressure determination across the surface being drilled has a significant effect on rate of penetration. Figure 1 shows the general relationship. An overbalance of 100 psi is considered to be the minimum safe pressure balance from the standpoint that should anything happen to the mud pumps or drillstring, the well would be controlled by the static mud weight. Higher penetration rates are possible at or below pressure balance but the expense of a gas kick and other failures generally overshadow the benefits. Yet, drilling at the appropriate balance is the most effective single factor in optimizing drilling cost.

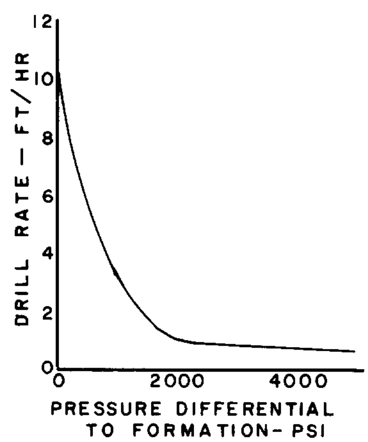

FIG. 1

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** NØV  73B **

THE ANALYSTS INC.
PØRE PRESSURE-PØRØSITY PRØGRAM

ADJ PP?Y=1 N=0 =0

DC WT=35
AVG RPM=100
HK LD=260
DPTH=11983
TVD=0
MUD WT=10.6
DIA=12.25
HARD=250
E FAC=.17
WT K=3.0
SHLE FAC=.6
RUN=450
BASE PØR=7
HALF FT?Y=1 N=0 =0
LCØ=.4
UCØ=.3
PØRE PRESS=10.3
MAX PØR=30
LITH K=16
BEAR W=0
MUD FAC=1.6
BIT CST=650
RIG RTE=450
RND FAC=1.1
TØT HRS=0
BIT S DPTH=11983
CUR TIME=16.0

INPUT:
 T=0 D=1 =0
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DEPTH	ROP	WT ON BIT	RPM	POROSITY	PORE PRESSURE (ppg)	TOOTH FLAT	DRILL STRENGTH	COST PER FOOT	HOURS ON BIT	"A" EXPONENT	MUD WT	BEARING WEAR
11965	14.17	37	101	7.4	10.32	.172	9.6	566.37	.0	10.40	10.7*	
11966	16.16	39	66	10.7	10.32	.173	6.2	400.50	.1	10.98		.0
11967	23.53	43	101	11.6	10.32	.175	7.6	305.15	.1	11.15		.0
11988	14.67	45	100	7.4	10.32	.177	9.8	250.17	.2	10.41		.0
11989	15.51	43	107	7.5	10.32	.160	9.7	213.31	.2	10.43		.1
11990	13.66	44	93	7.4	10.33	.162	9.7	167.53	.3	10.43		.1
11991	11.80	42	89	6.6	10.33	.185	10.1	166.65	.4	10.30		.1
11992	14.93	41	91	6.6	10.34	.166	9.0	153.44	.5	10.68		.1
11994	13.09	45	92	7.2	10.34	.189	9.6	126.67	.6	10.39		.2
11995	10.87	45	93	5.9	10.32	.191	10.6	121.39	.6	10.10		.2
11996	12.85	46	99	6.7	10.34	.194	10.2	114.74	.7	10.28		.2
11997	13.63	46	103	7.0	10.33	.197	10.0	108.91	.8	10.34		.3
11998	14.11	46	102	7.4	10.34	.199	9.7	103.77	.9	10.42		.3
11999	11.99	41	93	7.2	10.34	.201	9.6	99.63	.9	10.39		.3

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INPUT:
 T=0 D=1 =1

INPUT:
 T=0 D=1 =1
```

FIG. 2

Computer Technique

Detection of abnormal pore pressure and the interpretation of drilling data to give a reliable pore pressure at the bit have received considerable attention in the past 10 years. THE ANALYSTS, INC. of Houston developed a data collection system interfaced with a mini-computer and programmed to automatically calculate porosity and pore pressure. The porosity, pore pressure, bearing wear and other interpretations are printed as in Fig. 2 about 10 seconds after each foot is drilled. The computer output is plotted on depth as in Fig. 3 to give a porosity and pore pressure log.

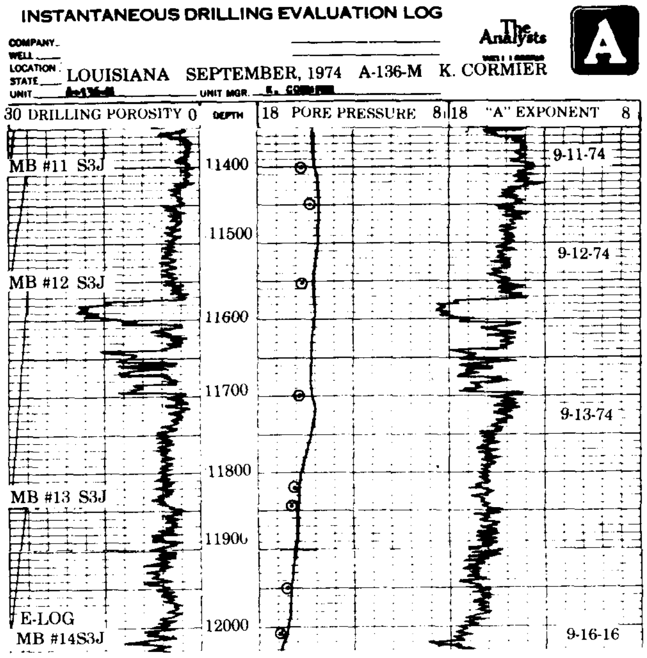

FIG. 3

Other Pressure Indicators

There are several pressure indicators worthy of mention, but space does not permit a thorough discussion of each. These include: *"d" exponent, torque, drag on connections, pump pressure, pit and flow indicators, erratic cuttings volume, hole fillup on trips, background gas, connection gas, shale density* and *chloride change* in the mud.

Mud flowline temperature is a recording of temperature as it leaves the wellbore at the flowline. Normally there is a two to three degree increase in temperature as abnormal pressure is approached. There are other important interpretations that can be made if heat transfer is understood and if temperature recording is done properly.

The earth's core is a basic heat source of several thousand degrees. Heat is conducted through each individual formation in the earth's crust at a rate that is in proportion to the thermal conductivity of that formation (Fig. 4). Each formation has oil, gas or water in pore spaces which changes its net thermal conductivity. Thermal conductivity of various formation components in units, (k = Btu per hour per sq ft per °F per foot temp. gradient) is as follows:

Substance	k
Water	0.343
Earth Soil Dry	0.075
Natural Gas	0.015
Oil	0.086
Dry Sand	0.188

Examination of this table shows that water has the highest thermal conductivity of all the materials encountered. We can conclude that heat flow rate through any segment of formation is proportional to the water fraction in the rock and temperature differential across it.

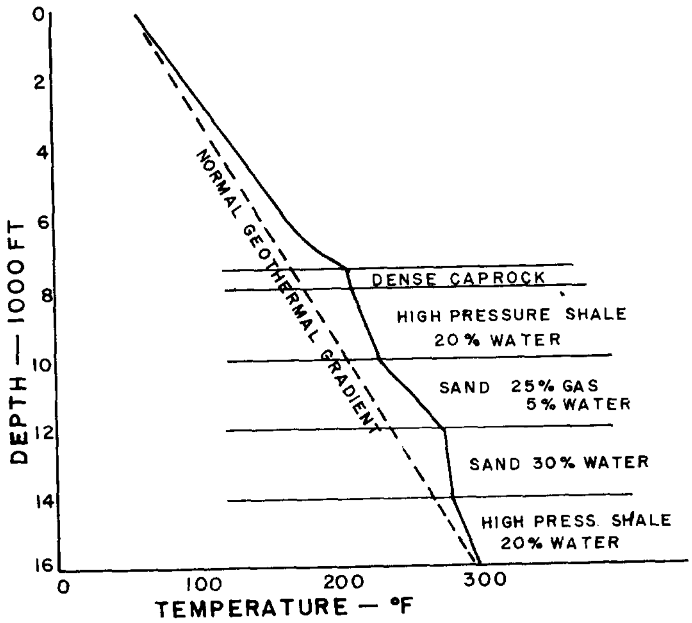

FIG. 4

As the bit touches any depth, the circulated mud carries the heat to the surface. Each anomaly at depth should be reflected in surface mud temperature. A log of these readings should show a significant temperature increase above abnormal pressure or across a gas sand. Once the overpressured shale is penetrated, the temperature change with depth should be very slight. The primary value of temperature in pressure detection is that it flows through the formation and may be the first indication that the bit is approaching abnormal pressure.

For temperature data to be properly applied, we must first have a temperature sensor that is placed in the mud flow where the probe responds to any change in temperature.

Swab Surge Analysis

Several pressure indicators involve gas, salinity or formation behavior that can be directly attributed to either pulling or running drill pipe or making connection. These drill pipe motions create a reduction in hydrostatic mud pressure; or an increase, depending on the direction of pipe motion. An understanding of these forces is essential to an effective interpretation of connection gas.

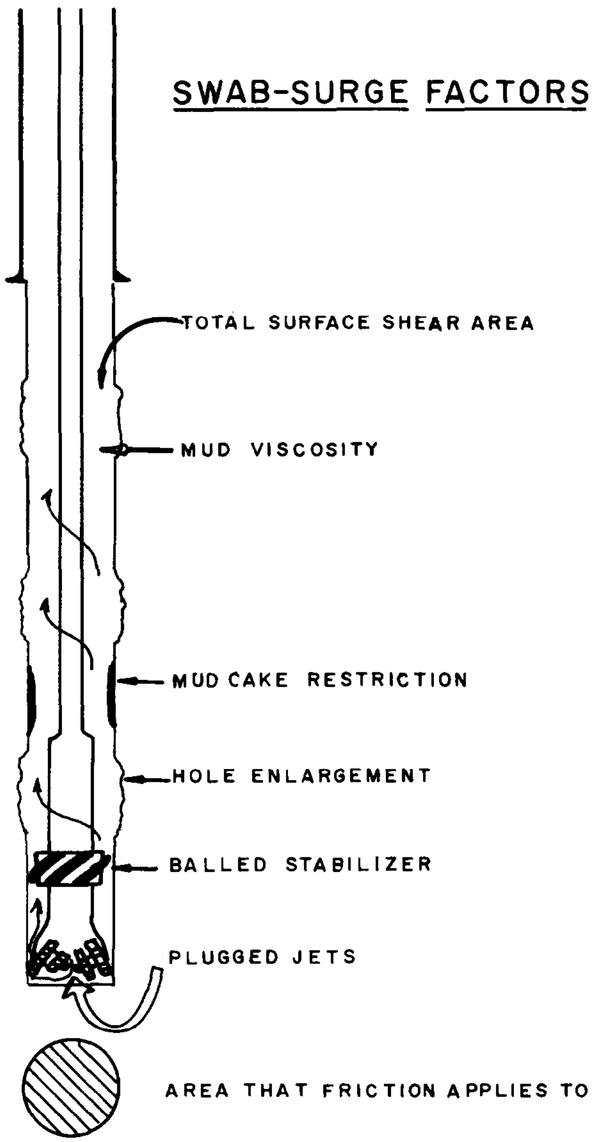

FIG. 5—SWAB-SURGE FACTORS

Figure 5 shows a general schematic of the system with the bit near bottom. During normal circulation the mud travels down the drillpipe and returns up the annulus. Pump pressure applied at the bit overcomes the total friction force up the annulus at any particular circulating rate. This frictional force applied at the bottomhole area increases the effective mud weight (equivalent circulating density). These frictional forces also lift the drillstring and can be observed on the weight indicator when the pumps are stopped. Knowing the annular velocity (the rate at which fluid moves by the drill pipe) and the change in drillstring weight, we may calculate the surge gradient at any velocity of moving the pipe through the fluid.

$$SG = \frac{\dfrac{(WT_1 - WT_2)(4)}{D_H^2\,(.0519)}}{\dfrac{GPM\,(0.133680)\,(4)\,(144)}{(D_H^2 - D_p^2)}}$$

$$SG = \frac{WT\,(D_H^2 - D_p^2)}{D_H^2\,(GPM)}$$

Surge at any depth of the bit while pulling or running the drillstring at a given second/stand is:

$$\text{Surge} = (SG)\,\frac{(D_B)\,(5400)}{(D_T)\,(\text{sec/stand})}$$

Where:
WT_1 = Wt of drillstring, pump off, lb
WT_2 = Wt of drillstring, pump on, lb
D_H = Diameter of hole, in.
D_p = Diameter of pipe, in.
GPM = Circulating rate at test, gal/min
D_T = Depth of bit during test
D_B = Depth of bit on trip out

The change in hook load observed for this test accounts for total net conditions of balled-up bit or stabilizers, low clearance of drill collars, out-of-gauge hole, and mud properties at downhole conditions. It also accounts for the net shear area which is somewhere between the outer surface of the drillpipe and the wall of the hole. Though shear area and length of pipe in hole are the major factors in surge pressure, they are difficult to calculate from mud properties. Figure 6 is a computer solution to this equation.

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THE ANALYSTS INC.
SWAB SURGE PROGRAM

INPUT OPTION:
0=METRIC
1=ENGLISH
ANSWER=1

DEPTH(FT)=14900
CHG IN HK LD=5
CIRC RATE(GPM)=290
HOLE DIAM(IN)=8.5
D PIPE(OD)=4.5

ECD AT TD=MW+ .11

DEPTH (X1000)	CHANGE IN MUD-PPG SECONDS/STAND											
	3	4	5	6	8	10	15	20	30	40	50	60
1	.10	.07	.06	.05	.03	.03	.02	.01	.01	.00	.00	.00
2	.20	.15	.12	.10	.07	.06	.04	.03	.02	.01	.01	.01
3	.30	.22	.18	.15	.11	.09	.06	.04	.03	.02	.01	.01
4	.40	.30	.24	.20	.15	.12	.08	.06	.04	.03	.02	.02
5	.50	.37	.30	.25	.18	.15	.10	.07	.05	.03	.03	.02
6	.60	.45	.36	.30	.22	.18	.12	.09	.06	.04	.03	.03
7	.70	.52	.42	.35	.26	.21	.14	.10	.07	.05	.04	.03
8	.80	.60	.48	.40	.30	.24	.16	.12	.08	.06	.04	.04
9	.90	.67	.54	.45	.33	.27	.18	.13	.09	.06	.05	.04
10	1.00	.75	.60	.50	.37	.30	.20	.15	.10	.07	.06	.05
11	1.10	.82	.66	.55	.41	.33	.22	.16	.11	.08	.06	.05
12	1.20	.90	.72	.60	.45	.36	.24	.18	.12	.09	.07	.06
13	1.30	.97	.78	.65	.48	.39	.26	.19	.13	.09	.07	.06
14	1.40	1.05	.84	.70	.52	.42	.28	.21	.14	.10	.08	.07
15	1.50	1.13	.90	.75	.56	.45	.30	.22	.15	.11	.09	.07

DEPTH(FT)=

FIG. 6

Gas Volumetric Analysis

Presence of gas in a circulating mud system, without further analysis, simply indicates that there is a hydrocarbon source in the exposed wellbore. An accurate conclusion as to how it entered the mud requires a skillful analysis of several factors. First let us consider the ways that gas may enter the mud. These are from two basic sources: (1) gas inflow due to underbalance and (2) gas that evolves from the drill cuttings. Unbalanced formation pressure or pressure reduction due to pipe motion can allow gas inflow.

Gas contributed from drill cuttings can reach alarming proportions in the mud yet be completely safe in control of pore pressure. A volumetric analysis of cuttings, mud circulation rate, and gas in the mud under surface conditions, is necessary to make an intelligent conclusion as to the source of gas.

First, the rock volume (Fig. 7) can be calculated for size of hole being drilled.

If the porosity is known, the pore volume space of that foot can be calculated. If porosity is not known, a porosity of 20% can be assumed for medium-to-tight sand formations in the Gulf Coast. From the rate of penetration we can determine the feet per minute and the cubic feet of mud that circulated by into which the pore space was added. Pore space gas will expand from

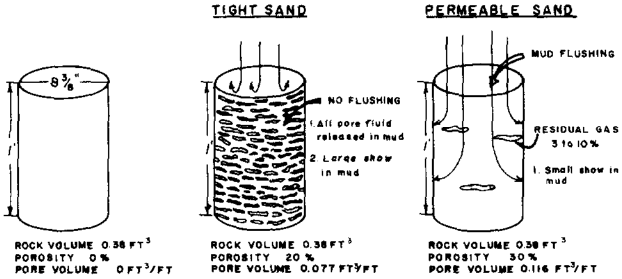

FIG. 7

bottomhole temperature and pressure conditions to surface temperature and pressure conditions. For example, at 11,000 psi bottomhole pressure, each cubic foot of pore space gas will expand to 550 cubic feet at the surface. If this is blended with 350 gal. of mud, gas cut would be 54% at the surface; or 12 ppg mud would be cut to 6.5 ppg.

These relationships can be determined rapidly with the graphical approach shown in Figs. 8 and 9. The curves to determine pore volume assume 20% porosity. The pressure-temperature multiplier uses normal geothermal temperature corresponding to a depth where normal pressure gradient would yield the corresponding pressures. The mathematics in the nomographs are rather crude, yet they provide a quick estimate of the maximum gas from cuttings that can be expected as the mud reaches the surface.

If gas measured at the surface exceeds this estimate, inflow would be suspected. If the gas was less than estimated, this could indicate that the porosity was less than 20%, that the sand was wet, or that vertical permeability was sufficient to allow hydrocarbons to be flushed out of the rock ahead of the bit. The amount of flushing depends on vertical permeability of the sand and overbalance pressure at the drilled surface.

In volumetric relationships the following conversions should be useful:

30 units gas HW = 1% gas in mud

30 units gas HW = 10,000 ppm gas in mud

300 units gas HW = 10% gas cut in mud (10 ppg cut to 9 ppg)

CONCLUSIONS

Well cost can be minimized by a combination of basic drilling technology and reliable pore pressure knowledge:

1. Select a bit designed to drill the formation ahead of it.
2. Apply sufficient weight to get maximum tooth penetration.
3. At shallow depth, limit rotary speed to match hydraulic cleaning capability. In medium-to-hard rocks, limit rotary speed to the point that chips are removed at each tooth impact. (40 to 80 RPM)
4. Select bit nozzles to give 3 to 4.5 horsepower per inch of hole diameter.
5. Run high water loss drilling fluid where practical, and control filtrate loss by pressure balance.
6. Select a reliable pore pressure detection service and apply the interpretations.
7. Maintain a mud weight as close to balance as possible with existing well control limits.
8. Interpret gas shows in mud with a volumetric procedure.

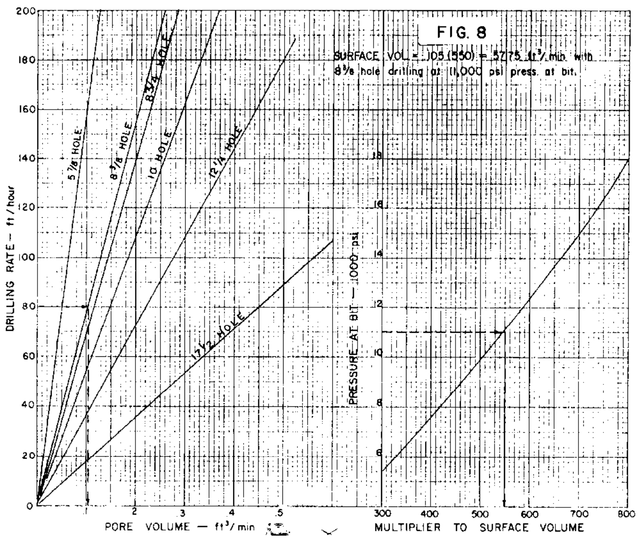

FIG. 8

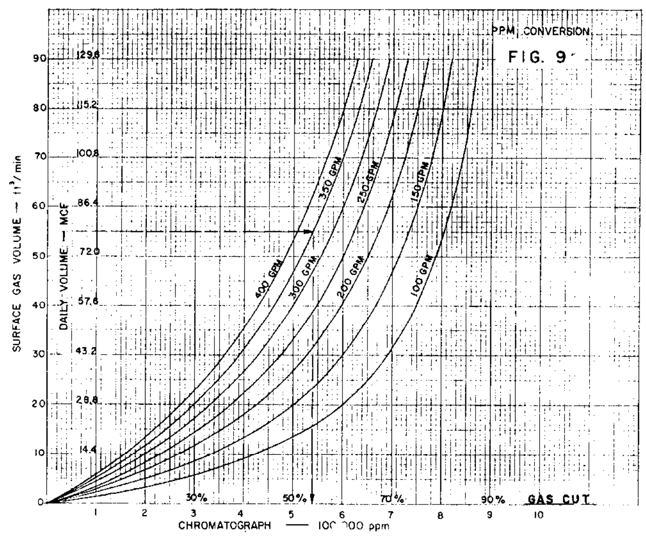

FIG. 9