A NEW MEANS OF DIAGNOSING PUMPING WELL PROBLEMS

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INTRODUCTION

In an every day review of well and reservoir performance there is a wealth of interpretive tools such as the one given in SPE Monograph No. 1 on build-up interpretation and in many articles in the SPE journals. Too often, however, the meager data available for analysis causes concern as to the reliability of the conclusions. A typical problem involves the declining production rate of older wells, where the engineer is faced with the problem of determining what remedial steps, if any, can be justified. Several possible problems come to mind.

1. The pump may not be operating efficiently.
2. Scale deposits may be forming in the well, causing skin damage.
3. The reservoir pressure may be lower than expected.
4. The formation may be tighter than expected.

This paper describes a new practical service for acoustically determining build-up curves for pumping wells. Included in the service is a rapid standardized analysis that provides the client with measures of pump efficiency, estimates of skin damage, formation permeability and reservoir pressure. Figure 23 shows a summary of the reservoir data obtained in this analysis.

DESCRIPTION OF SONIC WELL SOUNDER

Figure 1 shows a diagrammatic sketch of a typical wellhead hookup. The sounder is an automatic programmed echo device for measuring liquid levels. Nitrogen is stored in an expansion chamber at 30 - 50 psi above the well's surface pressure. A quick-opening, three-way valve allows a discharge into the well annulus causing a pressure surge that proceeds down to the liquid level and reflects back to the surface. A transducer picks up the first surge of gas through it, and the echo coming back. The first impulse starts a counter and the second stops it. The rate of the counter is controlled by input of the velocity of sound in microseconds per foot - on a dial. This setting, in practice, is such that the counter reads directly the depth in feet to a known reflector

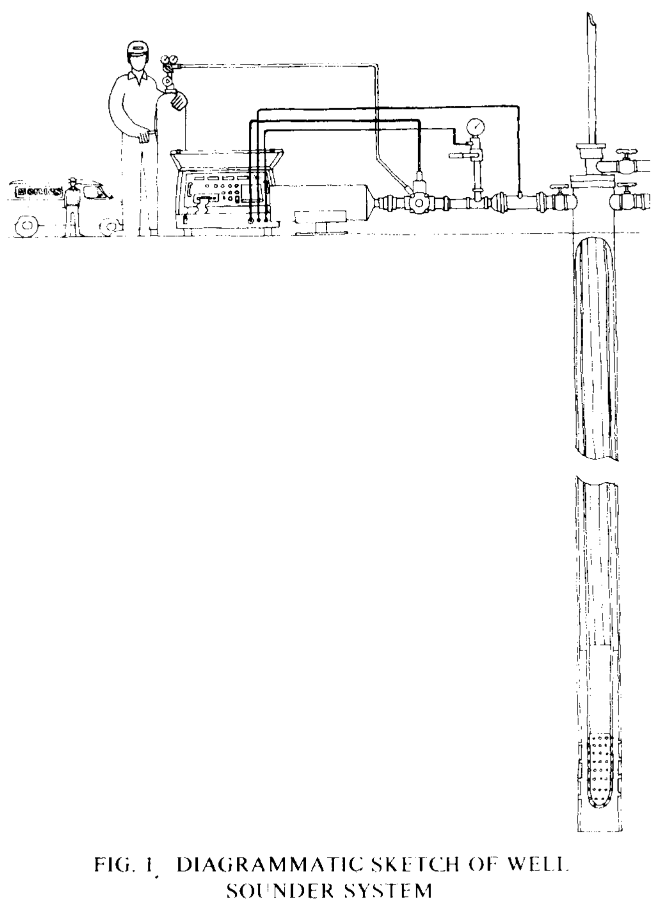

FIG. 1 DIAGRAMMATIC SKETCH OF WELL SOUNDER SYSTEM

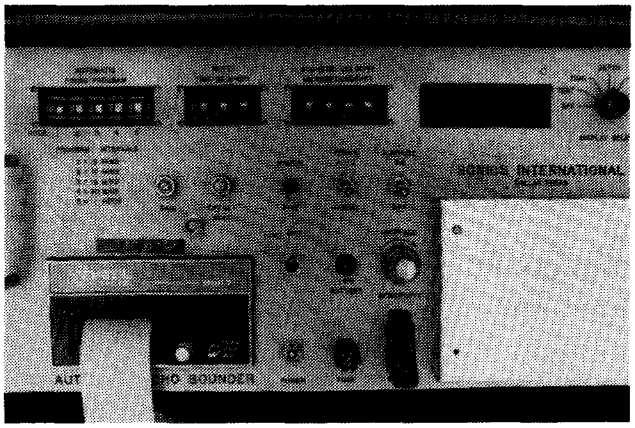

FIG. 2 —CLOSE UP OF THE CONTROL PANEL

at the bottom. After each discharge, 3 four-digit numbers are recorded on a paper tape. These are:

1. The time in minutes since the build-up started
2. The depth to liquid in feet
3. The surface pressure in psig.

For each of the first five hours, the frequency of measurement may be programmed at time intervals ranging from 5 - 60 minutes. Following this, the unit continues at the frequency set for the fifth hour. For intervals greater than 10 minutes, each recording is followed by a confirming measurement one minute later. For initial adjustment, or for checking rapid liquid level changes, it may be fired automatically at one-minute intervals or manually at any time.

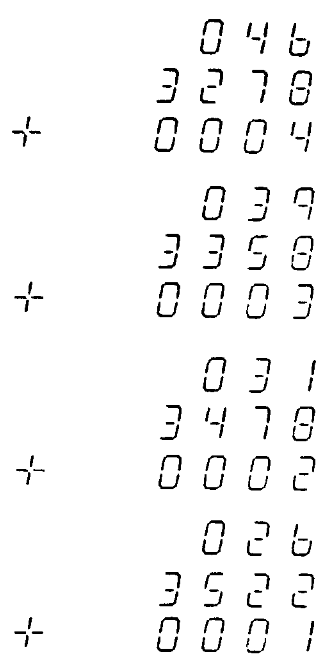

FIG. 3 RECORDING TAPE

Figure 2 shows the control panel of the unit. The firing frequency is programmed with the control at the upper left. The counter reads on the diplay at the upper right, and can be seen in action during the counting. It shows time, depth and surface pressure at the end of each count. All three are printed on the paper tape, Fig. 3 (lower left, Fig. 2). The third control from left inputs the acoustic velocity in microseconds per foot.

Loud reflections from reflectors close to the transducer, such as the entry into the annulus, shallow collars, etc., would turn the counter off almost immediately after firing if it were not for the mute time control. The mute time suppresses all signals after the starting impulse for up to 10 seconds. Normally, it is set for about one-third the

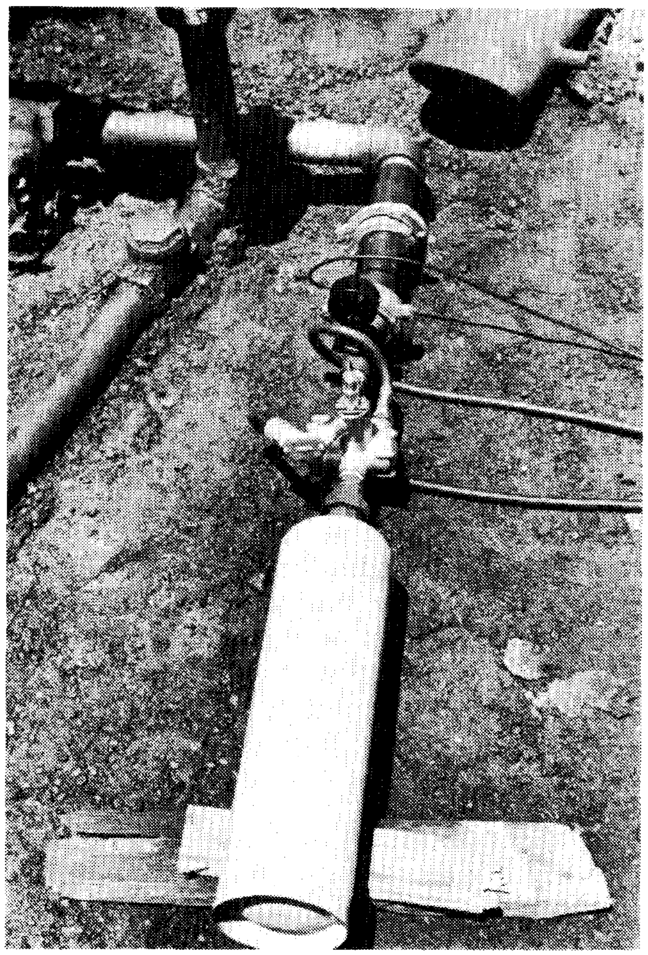

FIG. 4 EXPANSION CHAMBER 3-WAY VALVE AND TRANSDUCER CONNECTED TO WING VALVE

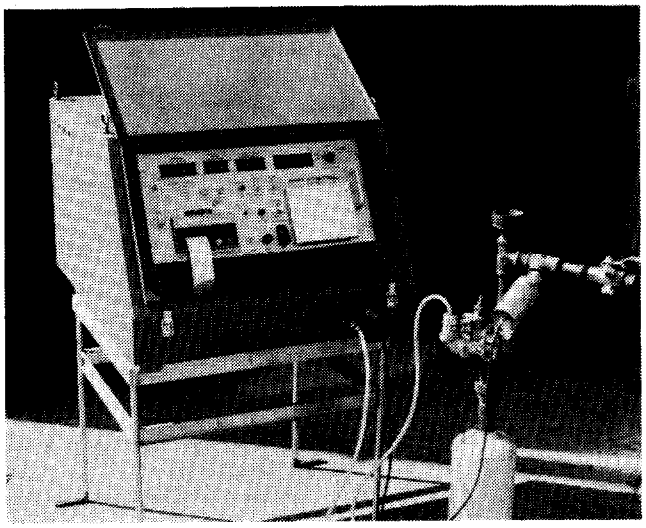

FIG. 5—SONIC WELL SOUNDER UNIT

distance down to the target reflector. It may be set lower if a larger reflector, such as the top of a liner, is found deep in the well.

Figure 4 shows a general view of the wellhead with the transducer, quick-opening valve and expansion chamber. Figure 5 shows the unit in a test frame at the lab.

The inherent characteristics of the Sonic Well Sounder allow the stabilized pumping performance to be observed followed by uninterrupted measurement of the build-up curve. It avoids the uncertainties due to dumping of the tubing contents at the moment of well shut-in and due to the delay incurred in beginning build-up measurements while the rods and pump are being removed.

INTERPRETATION OF DATA

The easiest way to see how the data are handled is through the examination of the tables and figures in this report.

Table I (Fig. 6) gives the well and field parameters obtained from the operator. This includes data on the pump for calculation of pump performance. Table II (Fig. 7) shows the data recorded by the unit in the field.

The next figure (Fig. 8) shows a build-up curve with the data points shown. Points are reproduceable to about 1-2 feet. This increases confidence in the measurement. Incidentally, if a well is flowing a high volume of gas through the annulus, it comes up in slugs, tending to cause the surface to rise and fall. Further, at times, foam on

** TABLE I ** GB1X

W E L L P A R A M E T E R S

WELL NAME: LEASE: NUMBER:

COMPANY:

FIELD:

COUNTY: STATE:

HOLE DATA:

CASING I. D. (INCHES): 4.95

TUBING O.D. (INCHES): 2.375

MID-PERFORATION DEPTH (FEET): 3578

PUMPING LIQUID DEPTH (FEET): 3513

RESERVOIR DATA:

POROSITY (%): 25.1

NET PAY THICKNESS (FEET): 6

TEMPERATURE (DEG F): 158

ACRES/WELL: 40

PRODUCTION DATA:

OIL (BBL/DAY): 20.5 GRAVITY (DEG API): 45

WATER (BBL/DAY): 62.38 SALINITY (MG/L): 2300

GAS (MCF/DAY): 5.658 GRAVITY:

SURFACE PRESSURE, PUMPING (PSIG): 42

PUMP DATA

PUMP I. D. (INCHES): 1.5

STROKE LENGTH (INCHES): 42

STROKES PER MINUTE: 12

FIG. 6—TABLE I

** TABLE II **

SONIC WELL SOUNDER FIELD DATA

SHUT-IN TIME (MINUTES)	DEPTH (FEET)	PRESSURE (PSIG)	SHUT-IN TIME (MINUTES)	DEPTH (FEET)	PRESSURE (PSIG)
0	4761	34.0	1073	4164	0.0
5	4752	35.0	1133	4135	57.0
10	4743	35.5	1193	4105	0.0
15	4737	36.0	1253	4077	0.0
20	4732	36.3	1313	4049	58.2
25	4727	36.7	1373	4020	0.0
30	4723	37.0	1470	3974	59.0
35	4719	37.5	1492	3968	59.5
40	4713	38.0	1493	3963	59.5
45	4708	0.0	1553	3935	0.0
50	4703	0.0	1613	3906	0.0
55	4699	0.0	1673	3878	60.0
60	4696	39.0	1733	3851	0.0
70	4691	0.0	1750	3839	60.5
80	4689	0.0	1794	3820	0.0
90	4683	0.0	1854	3795	0.0
100	4674	40.0	1913	3769	60.5
110	4666	0.0	1973	3744	0.0
120	4661	0.0	2033	3718	0.0
135	4654	0.0	2093	3693	60.7
150	4647	0.0	2153	3668	0.0
165	4638	0.0	2213	3642	60.9
180	4629	0.0	2237	3617	0.0
210	4613	44.0	2274	3616	0.0
216	4610	44.0	2304	3604	0.0
234	4596	0.0	2364	3598	61.0
294	4561	0.0	2375	3594	61.0
354	4529	0.0	2417	3573	0.0
371	4520	47.8	2486	3548	0.0
413	4497	0.0	2546	3524	61.0
473	4465	0.0	2606	3500	0.0
533	4439	51.0	2666	3476	0.0
593	4404	0.0	2726	3451	61.0
653	4374	0.0	2786	3427	0.0
713	4345	54.0	2818	3414	61.0
773	4314	0.0	2831	3407	61.0
787	4307	55.0			
833	4284	0.0			
893	4254	0.0			
953	4224	55.5			
1013	4194	0.0			

FIG. 7—TABLE II

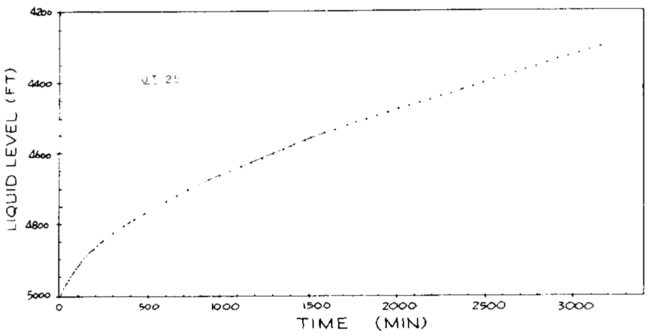

FIGURE 8

the surface tends to accumulate, tending to absorb the sound and leaving the counter running until it resets for the next shot. Since points are obtained frequently and systematically, one can normally obtain interpretable curves even with occasional gaps attributed to foam.

Table III (Fig. 9) shows the basic interpretation of the data. The first three columns are time, depth and surface pressure taken from the complete table of data (Table II, Fig. 7). In this case, differences between successive data are used in calculations; therefore, it is desirable to pick 20 or 30 points distributed along the curve, representing typical values for the analysis. Table III (Fig. 9) shows 20 such points (first three columns). Column 4 shows the pressure calculated at mid-perforations. This is calculated as shown in Fig. 10.

TABLE III

DATE (MMDDYY) 120575
FILE NAME: UTV1

CALCULATION OF PRESSURE AT PERFORATIONS AND
AFTERFLOW INTO WELL

PARAMETERS-
CSG ID, IN= 4.950, TBG OD, IN= 2.375
MID PERF DEPTH= 4955.0, % POROSITY= 10.00
NET FT PAY= 36.0, RES DEG F= 110, ACRES/WELL= 40.0
OIL B/D= 22.00, DEG API= 29.0
WATER B/D= 17.00, SALINITY MG/L= 90000, MCF/D= 11.000

BUILD-UP CURVE

SHUT IN TIME MINUTES	LIQUID LEVEL FEET	SURFACE PRESSURE PSIG	PRESSURE AT 4955.0 FT PSIA	FREE GAS ----INTO WELL------- MCF/D	OIL+WTR B/D	TOTAL B/D
.00	4761.00	34.00	107.77	11.000*	39.000*	306.171*
30.00	4723.00	37.00	128.78	4.761	26.645	123.413
60.00	4696.00	39.00	141.44	3.156	19.212	77.615
100.00	4674.00	40.00	151.65	1.178	11.911	32.240
210.00	4613.00	44.00	176.30	1.691	11.983	37.088
371.00	4520.00	47.80	212.82	1.075	12.526	25.752
533.00	4439.00	51.00	244.26	.884	10.856	20.328
713.00	4345.00	54.00	280.01	.730	11.347	18.170
953.00	4224.00	55.50	324.00	.266	10.974	13.124
1133.00	4135.00	57.00	356.32	.347	10.760	13.311
1313.00	4049.00	58.20	387.47	.272	10.400	12.238
1493.00	3963.00	59.50	418.62	.289	10.400	12.204
1673.00	3878.00	60.00	448.89	.109	10.284	10.917
1913.00	3769.00	60.50	487.30	.079	9.892	10.317
2093.00	3693.00	60.70	513.97	.041	9.157	9.408
2213.00	3642.00	60.90	531.86	.061	9.257	9.558
2364.00	3598.00	61.00	547.31	.024	6.347	6.462
2546.00	3524.00	61.00	573.06	0.	8.857	8.857
2726.00	3451.00	61.00	598.44	0.	8.835	8.835
2831.00	3407.00	61.00	613.73	0.	9.129	9.129

*THESE INITIAL VALUES ARE FROM PRODUCTION DATA

FIG. 9—TABLE III

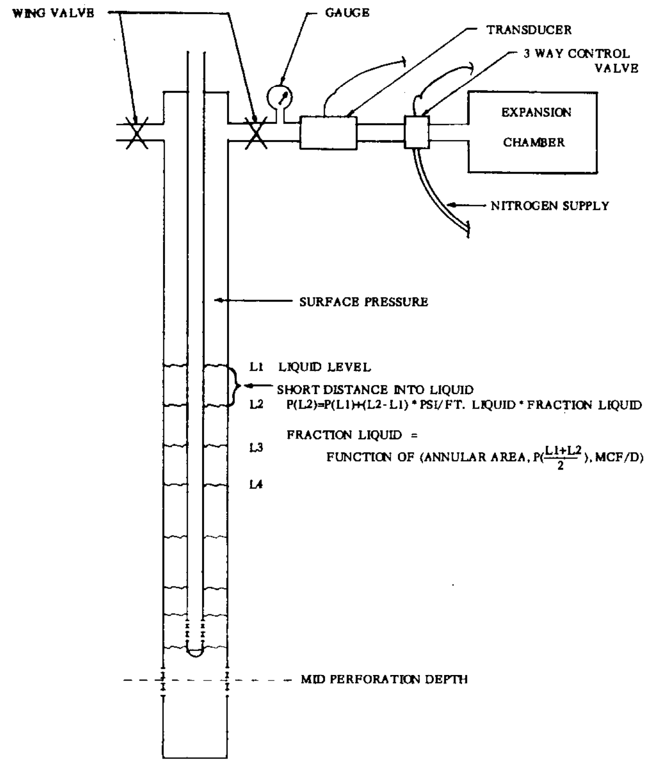

FIGURE 10

At each time interval, the bottomhole pressure is calculated. This depends upon the hydraulic gradient of the liquid which is a function of water salinity, oil gravity and water-oil ratio (produced ratio). In general, gas is rising through the liquid column so that its gradient also depends upon the fraction of the column which is liquid. The fraction of the liquid is a function of the annulus area, the gas rate, and the pressure. Starting at the top of the liquid column where the pressure is known, the fraction of the column which is liquid is calculated for a short element of the liquid column to determine pressure at the bottom of the element. This process is continued step by step until the mid-perforation depth is reached. The gas rate at time zero is the produced rate. After the first interval, the calculated gas afterflow as given in column 5 (Table III, Fig. 9) is used to correct for gas flow.

Gas afterflow is calculated from the rise in gas pressure, column 3 (Table III, Fig. 9). Knowing the sizes of casing and tubing and the depth of liquid, the volume in cubic feet corresponding to the pressure rise is calculated. Knowing the time interval, the rate

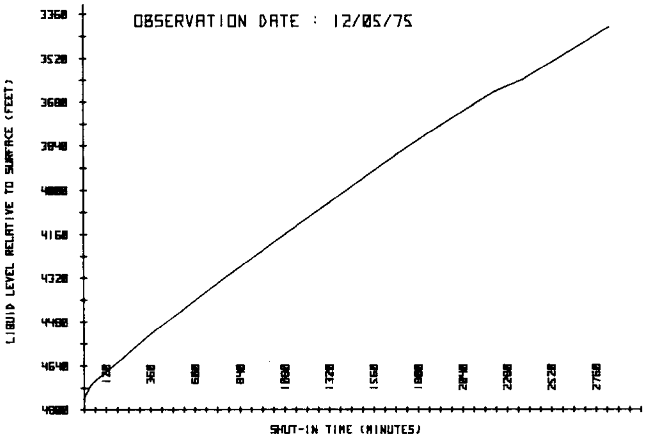

FIG. 11—LIQUID LEVEL VS SHUT-IN TIME

in MCFD is calculated. The effect of change in liquid level during the interval is also taken into account, although this usually turns out to be small. The liquid afterflow, column 6, is calculated from the annular area and the rise in liquid level, multiplied by the fraction liquid in the bottom of the well for this interval as calculated in column 4. The final column is simply the gas plus liquid afterflow calculated in BPD at mid-perforations.

Data plotted on an example well are included in this paper as Figs. 11 - 18.

Figure 11 shows an almost straight line for liquid influx, meaning that, in this example, liquid influx is almost independent of back pressure. This suggests the presence of two zones open to the well; one, providing most of the flow at low pressure, rapidly decreases as bottomhole pressure starts to rise; while the other from a tighter, higher-pressure, less compressible zone, continues to flow into the well.

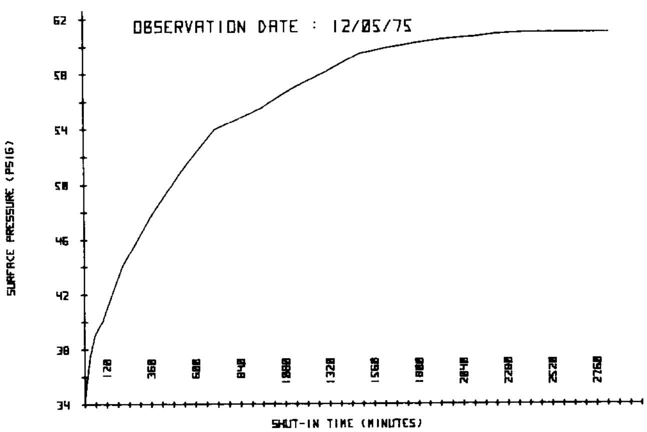

FIG. 12—SURFACE PRESSURE VS SHUT-IN TIME

Figure 12 shows the build-up of surface pressure used in calculation of gas afterflow and of pressure at mid-perforations. Figure 13 shows the pressure at mid-perforations which is used for the reservoir calculations.

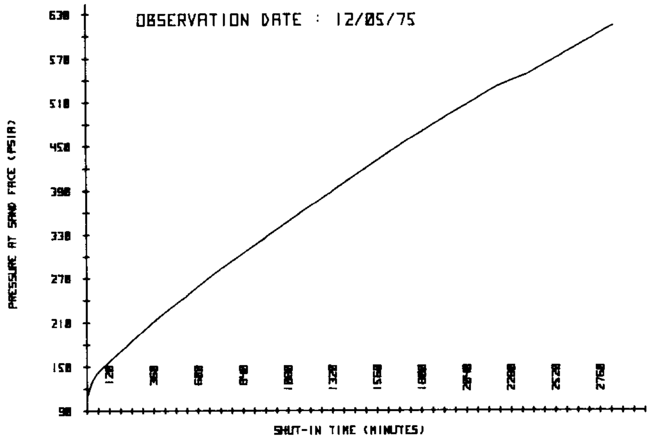

FIG. 13—PRESSURE AT MID-PERF DEPTH VS SHUT-IN TIME

Figure 14 shows the gas afterflow. The gas rate dropped very fast at first and then gradually dropped to zero in about 2 days (2880 min).

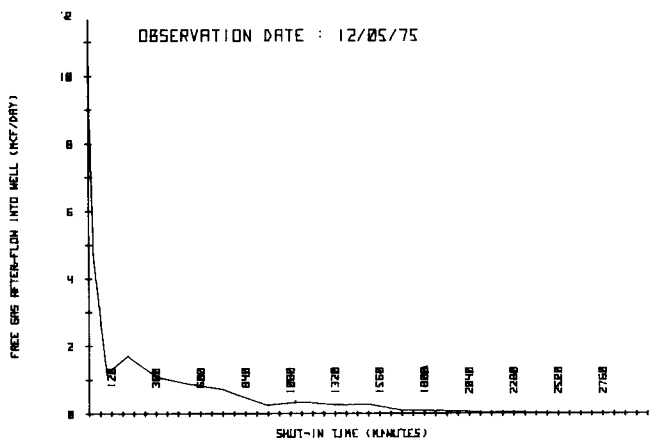

FIG. 14 FREE GAS AFTER-FLOW VS SHUT-IN TIME

Figure 15 shows the liquid afterflow which drops rapidly at first and then slowly, but doesn't drop to zero as was evident from Fig. 9 (Table III).

Figure 16 shows the total afterflow. This is used in calculating the well storage factor in barrels of afterflow per psi rise.

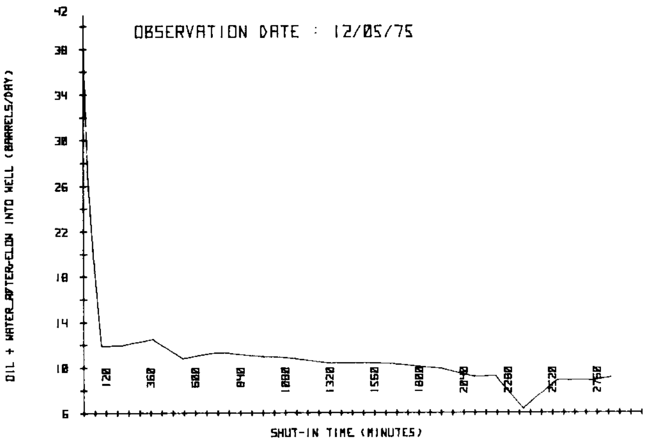

FIG. 15—OIL + WATER AFTER-FLOW VS SHUT-IN TIME

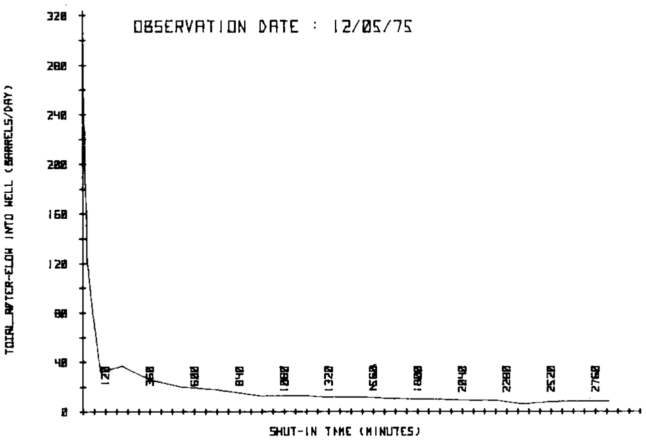

FIG. 16—TOTAL AFTER-FLOW VS SHUT-IN TIME

Figure 17 is the conventional semi-log plot of pressure at mid-perforations against log time. The value of M, psi/log cycle, is given for use in the permeability calculation.

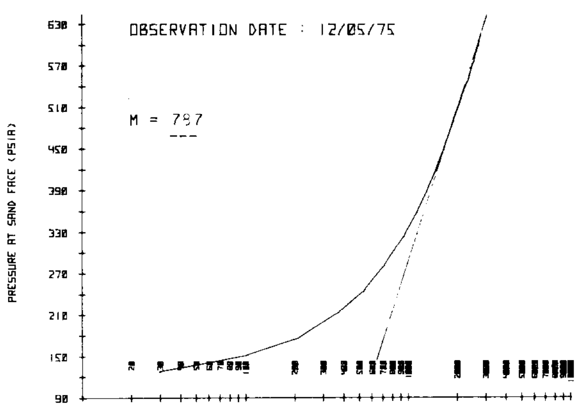

FIG. 17—MID-PERF PRESSURE VS LOG (T) EVAULATION OF KH

Figure 18 is used in estimating the reservoir inflow and the casing draw-down rate. The example well was controlled by an automatic "pump-off" device. Lines are drawn which give feet of rise or fall per minute for reservoir inflow or casing draw-down rate. This information is used in calculating pump efficiency and in determining the proper "on-off" settings if the well is on a time clock. It will also call attention to unexpectedly high pumping liquid levels. When a pump is running 24 hours a day (Fig. 19), we use the initial inflow, the inflow at the end of the build-up and initial casing draw-down as well as stabilized pumping rate to calculate pump efficiency.

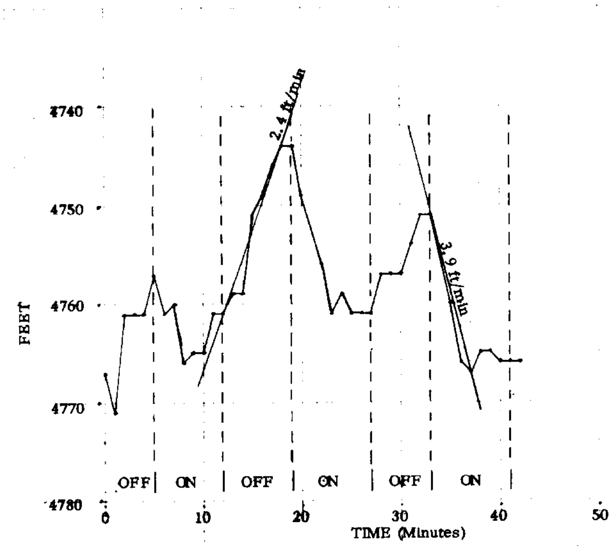

FIG. 18—PUMP DRAW-DOWN & RESERVOIR INFLOW

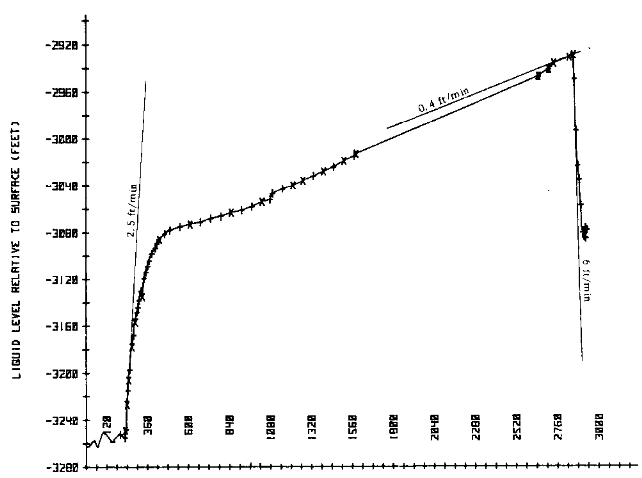

FIG. 19—LIQUID LEVEL VS SHUT-IN TIME

Table IV (Fig. 20) gives reservoir properties (saturations, mobilities and compressibility) calculated from production data and generalized relative permeability curves. These curves are picked on the basis of permeability calculated from the M value shown in Fig. 17. These curves and estimated viscosities permit calculation of the oil, water and gas saturation in the reservoir and the mobility (relative permeability/viscosity) for three-phase and for two-phase flow (columns 5 and 6). The reservoir compressibility depends mainly on the gas saturation and pressure, and is given in column 7.

TABLE IV

THREE PHASE FLOW: CALCULATION OF
SO, SW, SG, (KR/U)LIQUID, (KR/U)TOTAL,
RESERVOIR COMPRESSIBILITY AND DIFFUSIVITY
AS A FUNCTION OF PRESSURE, FOR:

MMDDYY 120575
FILE NAME: UTV1

INPUT PARAMETERS:
K= 5MD, PHI=10.0PCT, GLR= 282SCF/B, WOR= .77BBL/BBL
OIL WT=29.0DEG API, RES TEMP= 110DEG F, FLBHP= 108PSIA
SIBHP= 500PSIA

CALCULATED CONDITIONS
IRREDUCIBLE WATER = 54.8 PCT
DENSITY OF OIL-WATER MIX = .9332 GR/CC PSI/FT= .4049

FUNCTIONS FOR THREE-PHASE FLOW VS PRESSURE

PRESSR PSIA	SATRTNS IN PCT SO	SW	SG	MBLTY IN(1/CP) TOTAL	LIQUID	TOTAL COMP (1/PSI)	DIFSVTY FT**2/HR
108	25.5	69.3	5.2	.3076	.0386	1.7063E-03	2.277
127	25.6	69.4	4.9	.2726	.0400	1.4214E-03	2.422
147	25.7	69.6	4.7	.2463	.0412	1.2145E-03	2.562
167	25.8	69.6	4.5	.2259	.0423	1.0575E-03	2.698
186	25.9	69.7	4.4	.2095	.0434	9.3436E-04	2.832
206	25.9	69.8	4.3	.1961	.0444	8.3530E-04	2.966
225	26.0	69.9	4.1	.1850	.0454	7.5390E-04	3.100
245	26.0	70.0	4.0	.1756	.0463	6.8585E-04	3.234
265	26.0	70.0	3.9	.1676	.0472	6.2813E-04	3.370
284	26.1	70.1	3.8	.1607	.0481	5.7857E-04	3.508
304	26.1	70.2	3.8	.1547	.0489	5.3556E-04	3.648
323	26.1	70.2	3.7	.1494	.0498	4.9789E-04	3.791
343	26.1	70.3	3.6	.1448	.0506	4.6463E-04	3.936
363	26.1	70.3	3.6	.1407	.0514	4.3506E-04	4.085
382	26.1	70.4	3.5	.1370	.0523	4.0859E-04	4.237
402	26.1	70.5	3.4	.1338	.0531	3.8476E-04	4.392
422	26.1	70.5	3.4	.1309	.0539	3.6321E-04	4.552
441	26.1	70.6	3.3	.1283	.0547	3.4362E-04	4.715
461	26.1	70.6	3.3	.1259	.0555	3.2573E-04	4.883
480	26.1	70.7	3.2	.1238	.0563	3.0934E-04	5.055
500	26.1	70.7	3.2	.1219	.0571	2.9427E-04	5.231

END.

FIG. 20—TABLE IV

Table V (Fig. 21) shows the barrels per psi well storage calculated from the total afterflow and the change in psi. The Ramey dimensionless compressibility, $\overline{C}$, is one-half the ratio of the well storage to the storage capacity of a section of reservoir the size of the borehole.

Figure 22 shows the families of Ramey curves of log dimensionless pressure as log dimensionless time. Each family of curves is a function of $\overline{C}$. Having calculated $\overline{C}$, the family of curves can be indentified. For a given $\overline{C}$, a computer program gives the root mean square (RMS) deviation of the best fit of the build-up curve (Fig. 13) with a Ramey

TABLE V

CALCULATION OF WELL STORAGE AND RAMEY C VALUES
FOR EACH TIME INTERVAL:

PARAMETERS-
CSG ID, IN= 4.950, TBG OD, IN= 2.375
OIL B/D= 22.00, WATER B/D= 17.00, DEG API= 29.0
SALINITY MG/L= 90000, MID PERF DEPTH= 4955.0, MCF/D= 11.000
% POROSITY= 10.00, NET FT PAY= 36.0, RES DEG F= 110
RES COMPRESSIBILITY, PER PSI= 4.351E-04

FILE NAME UTV1
MMDDYY 120575

SHUT IN TIME MINUTES	PRESSURE AT 4955.0 FT PSIA	TOTAL FLOW INTO WELL B/D	WELL STORAGE B/PSI	RAMEY C COMPRESSIBLTY ----
30.00	128.78	123.413	.0200	102.52
60.00	141.44	77.615	.1277	655.93
100.00	151.65	32.240	.0876	450.07
210.00	175.30	37.088	.1150	590.31
371.00	217.82	25.752	.0788	404.81
533.00	244.26	20.328	.0727	373.47
713.00	280.01	18.170	.0635	326.27
953.00	324.00	13.124	.0497	255.31
1133.00	353.32	13.311	.0515	264.40
1313.00	387.47	12.238	.0491	252.12
1493.00	418.62	12.204	.0490	251.48
1673.00	448.89	10.917	.0451	231.53
1913.00	487.30	10.317	.0448	229.84
2093.00	513.97	9.408	.0441	226.45
2213.00	531.86	9.558	.0445	228.56
2364.00	547.31	6.462	.0439	225.26
2546.00	573.06	8.857	.0435	223.19
2726.00	593.44	8.835	.0435	223.50
2831.00	613.73	9.129	.0435	223.50

AVE RAMEY C= 302.0

FIG. 21—TABLE V

curve of a given value of S (skin effect). The skin value which gives the minimum RMS deviation curve fit is the skin effect for the well.

RESERVOIR ENGINEERING RESULTS

A computer program presents the reservoir engineering results together with the equations involved (Fig. 23). Included are:

Skin Damage

In addition to the Ramey curve fit skin value, the skin is also determined in the conventional manner from the semi-log extrapolation to P (1 hour).

Formation Permeability

The Ramey curve fit provides two permeability estimates: one based on the match point to dimensionless time, and one to dimensionless pressure. (To the extent that the Ramey values do not check, it raises a question as to the validity of the application. In general, the semi-log plot seems to give larger values than the Ramey curve fit, perhaps because it is dominated by condition at the end of the build-up; that is, farther out in the reservoir where relative permeability is better.) Permeability

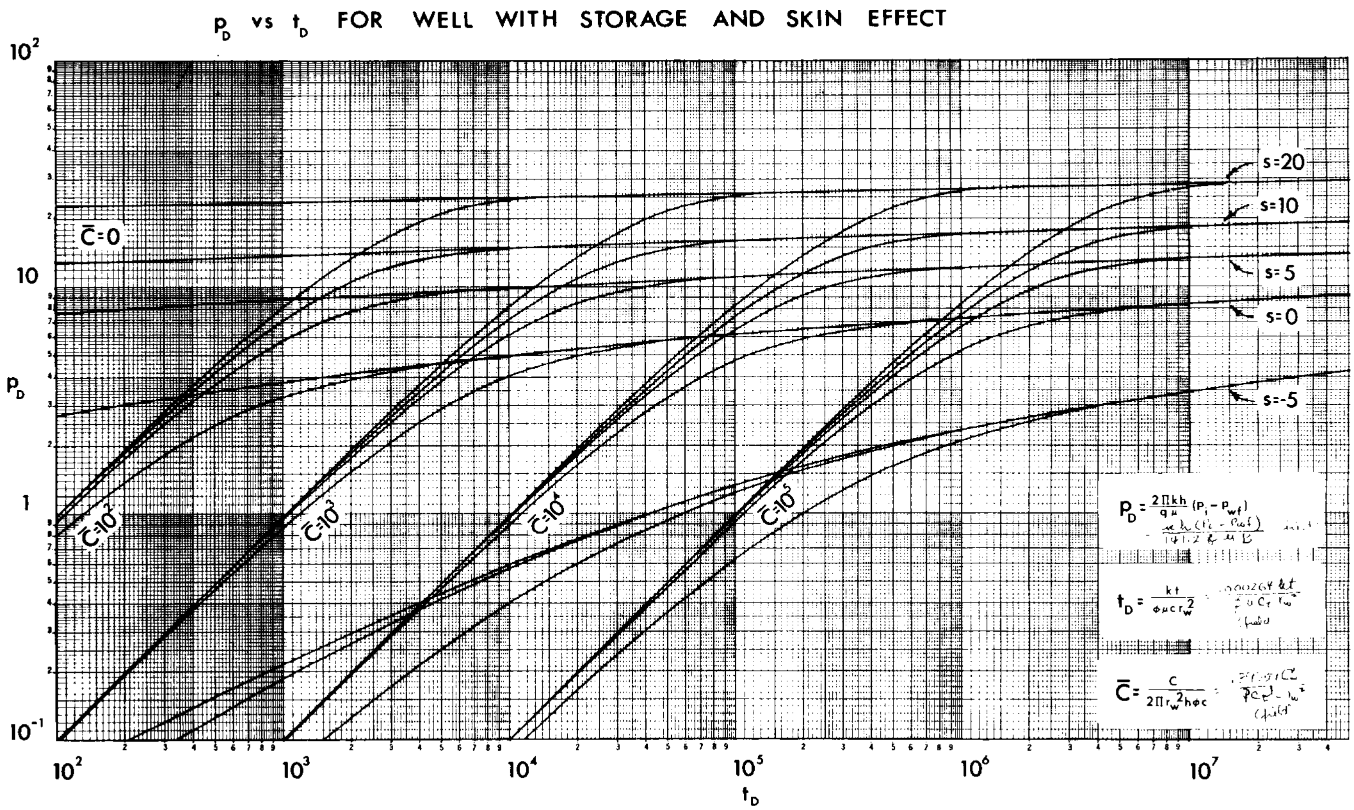

FIG. 22 RAMEY DIMENSIONLESS CURVES

is also calculated from the slope of the semi-log plot.

Reservoir Pressure

The pressure drop in the reservoir at the end of the build-up curve is calculated assuming pseudo-steady-state flow from the average distance of flow to the radius of investigation. This pressure drop is added to the final bottomhole pressure to get the reservoir pressure. The radius of investigation is the distance from the well for which the pressure has essentially equalized at the end of the build-up.

Productivity Indices

Productivity indices (PI) for oil, water and gas are given based on the production rates, reservoir pressure and flowing pressure. The change in PI's from year to year should give a good indication of any increase in blockage near the well.

SUMMARY

In summary, this new service provides evaluation of pump performance and a pressure build-up curve at low cost without need to remove rods and pump. The report includes an analysis of pump efficiency, estimates of skin damage, reservoir permeability and reservoir pressure. Considerable incidental information of interest to engineers making other studies is included. All data taken is included in the report so that the client can check the results presented with those computed using his own methods. For large companies with reservoir simulators, this should provide a way of upgrading their input from pumping wells.

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                         S U M M A R Y
                         = = = = = = =

                    SONIC WELL SOUNDER EXAMPLE

            ** S O N I C   W E L L   S O U N D E R **
                 A N A L Y S I S   R E P O R T

                        ** INPUT DATA **

F, % POROSITY  = 10   ; H, PAY THICKNESS (FT) = 36
M, PSI/CYCLE = 787  ; A, ACRES/WELL = 40
MOBILITY: TOTAL = K3 = 0.1407  ;LIQUID = K2 = 0.0514
RESERVOIR COMPRESSIBILITY, TOTAL = C = 4.35000E-04
T(DIMENSIONLESS) = T0 = 431.4   ; T(MINUTES) = T1 = 3080
T(FINAL)=T2= 2831       DEL P=P3= 122.5      RAMEY C=C1= 300
BOTTOM-HOLE PRESSURE (FLOWING) = 1228.78    ; BHP (FINAL) = 613.73
OIL B/D=Q1= 22    WATER B/D=Q2= 17    GAS MCF/D=Q3= 11

                    ** SUMMARY OF RESULTS **

* SKIN DAMAGE
    FROM P VS LGT(T)
         S1=1.151*((P1HR - PWF)/M -LGT(K5*K2/(F/100)/C/(1/9)+3.23)
         P1HR= -703.5      S1=      -8.2
    FROM RAMEY CURVE FIT
         S = <   -2.0

* PERMEABILITY -- FROM RAMEY CURVE FIT
    FROM DIFUSIVITY
         K6= (F/100)*C*RW↑2/(.000264*K3)*T0/(T1/60)
         K6=     0.62      K6*H =      22.1
    FROM DIMENSIONLESS PRESSURE
         K7=141.2*(Q1+Q2)*B*/(H*K2)*PDIM/P3
         K7=    36.68      K7*H=    1320.5

* PERMEABILITY --  FROM P VS LOG(T) PLOT
    K5= 162.6*(Q1+Q2)*B/(M*H*K2)
    K5=     4.57      K5*H =     164.60

* RADIUS OF INVESTIGATION
    R = SQR(.000264*K5*K3*(T2/60)/(.25*(F/100)*C))
    R =     27 FEET

* PRESSURE DROP ACROSS SKIN
    PSKIN = 141.2*(Q1+Q2)*B/(K5*K2*H)*S1
    PSKIN = -5618 PSI

* PRESSURE DROP IN RESERVOIR FROM RADIUS OF DRAINAGE TO
  RADIUS OF INVESTIGATION
    AVE RADIUS OF DRAINAGE=R2=SQR(43560*A/2/PI)=  527 FT
    RESERVOIR DELTA P = 141.2*(Q1+Q2)*B/(K5*K2*H)*LN(R2/R)
    RESERVOIR DELTA P =  2027 PSI

* ESTIMATED RESERVOIR PRESSURE
    P = (FINAL SHUT-IN PRESSURE) + (RESERVOIR DELTA P)
    RESERVOIR PRESSURE ESTIMATE =  2640 PSIA

* PRODUCTIVITY INDEX
    PI = (B/D OR MCF/D)/(P RESERVOIR - BHP PRODUCING)

    PI (OIL) =      0.0156 BBLS/DAY/PSI
    PI (WATER) =    0.0120 BBLS/DAY/PSI
    PI (GAS) =      0.0078 MCF/DAY/PSI

DONE SUMRY
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FIG. 23—SUMMARY