NOISE LOG APPLICATIONS IN WEST TEXAS

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INTRODUCTION

Liquid or gas flowing in a well generates a complex group of audible sound frequencies. Two-phase flow, which was gas bubbling through water behind uncemented casing, produced the frequencies shown on the curve in Fig. 1. An output signal from a piezoelectric transducer placed inside the casing has an alternating frequency waveform. The waveform is a composite of all the frequencies shown on the graph. Each frequency has a millivolt amplitude, varying with time, which contributes its relative amount to the total millivolt amplitude of the waveform. Using the optimum time interval, it is usually possible to obtain a good average amplitude measurement of these changing frequencies. The area under the curve in Fig. 1 is proportional to the millivolt amplitude for all of the frequencies above 200 Hz.

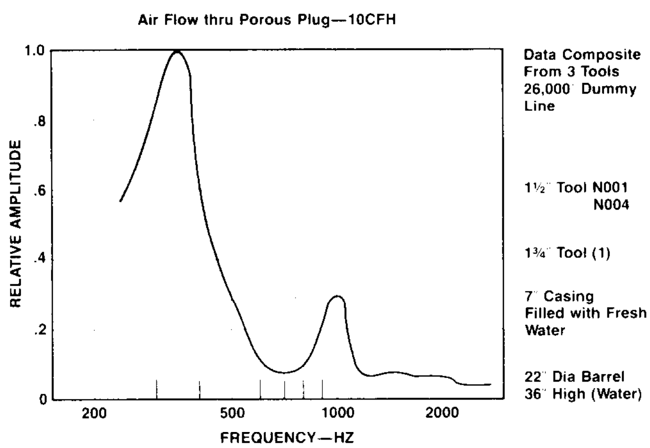

FIG. 1—NOISE SPECTRUM OF AIR FLOWING THROUGH A POROUS CHOKE AT 10 CFH INTO A BARREL OF WATER.

Extending a vertical line through 600 Hz, all of the area under the curve to the right is proportional to a millivolt amplitude of all frequencies above 600 Hz. These same comparisons can be made for 1000 and 2000 Hz. It is readily seen that, as filters remove frequencies from the amplitude measurement, the subsequent amplitude levels will always be less. These four filtered amplitude measurements are the four points which are plotted versus depth on semi-log paper to produce a four-curve noise log. Most of the interpretation involves a relative comparison which makes it desirable to establish fluid flow and "dead well" intervals.

With reference to Fig. 1, comparing the area under the curve on the low frequency end to the area for those frequencies above 600 Hz indicates two-phase flow has more energy associated with the low frequencies. The single-phase curve has more area associated with the 1000 and 2000 Hz end. The higher the differential pressure the greater the area under the high-frequency end. The conclusions from these data are that separation of the 200 from the 600 Hz curve indicates two-phase flow, and pronounced peaks on the 2000 Hz are an indication of differential pressure.

The high noise level associated with wireline and tool movement requires that all data be recorded during a time when the tool is stationary.

To facilitate the interpretation for a shut-in run, it is necessary to eliminate all lubricator, wellhead and wing valve leaks.

EQUIPMENT AND PRINCIPLES OF OPERATION

The downhole logging tool, Fig. 2 is 1-1/2 in. in diameter and 6 ft long. The bottom 2 ft has a piezoelectric crystal sound detector section, which is oil-filled for pressure compensation. In the middle, there is an integrated circuit, low noise preamplifies with a gain of 50. A second-stage operational amplifier drives the solid-state line matching circuit and has a gain of 40. The second stage has a plug-in feature which can reduce the gain of 2000 by a factor of 10. This gain feature makes it possible to use the same tool in wells that have low noise level or high noise generated by several MMCFD of gas flowing past the tool.

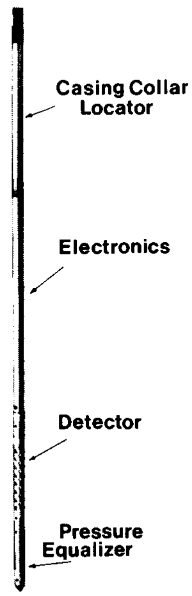

FIG. 2—DOWNHOLE TOOL

The panel in Fig. 3 has the four filter circuits referred to in the Introduction (200, 600, 1000 and 2000 Hz). The four digital AC voltmeters register the four values of noise levels from the filters simultaneously. It is possible to put the four meters on hold and have the noise level values remain on the meters while the tool is moved to the next station. The panel is equipped with a speaker and a jack for high-fidelity earphones. There are two other filters in the panel (4000 and 6000 Hz) for sand detection study.

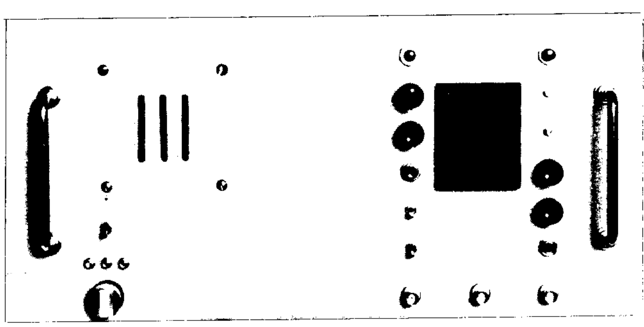

FIG. 3—NOISE LOG PANEL

NORMALIZING LOG DATA

There are several factors that influence the amplitude of a signal waveform from a standard source. When these factors are changed, the millivolt noise level on the various curves must be compensated or normalized to retain the standard millivolt amplitude.

L_f - Line factor, depending upon the wireline diameter and length.

0.09/1000 ft - 5/16-in. dia.
0.1/1000 ft - 7/32-in. dia.

T_f - Tool gain factor which is 2.5 for all tools.

W_g - Well geometry factor shown in Table 1

As an example from Table 2 data:

MV is the peak-to-peak millivolt amplitude from the curve of interest on the log.

N_{1000Hz} is the MV reading that has been normalized.

$N_{1000Hz} = MV \times T_f \times L_f \times W_g$; P-P millivolts.

$5(N_{1000Hz} - 6)$ This step is to obtain the product: $(\bar{q})(\Delta P)$.

$\bar{q}$ is the flow rate at the bottomhole pressure in MCFD.

ΔP is the differential pressure at the source in psi.

Solving the equation:

$$\bar{q} = \frac{5(N_{1000Hz} - 6)}{\Delta P}$$

and selecting the proper power of 10 for the ΔP will give an answer in CFD.

For gas production to obtain standard cubic feet at the surface,

$$q = \bar{q}\,\frac{(BHP + 14.7)}{14.7}$$

$$q = SCFD$$

For liquid production,

$$q = \bar{q} / 5.6 \text{ BPD}$$

TABLE 1 WELL GEOMETRY FACTOR

TYPE OF WELL	FLUID CONTENT	FACTOR
Tubingless Completion	Liquid in String	1.0
"	Gas in String	1.2
Tubing String in Casing	Liquid in Tubing Liquid in Annulus	2
"	Gas in Tubing Liquid in Annulus or Vice Versa	2-4
"	Gas in Tubing and Annulus	5-10
Leak into Same String as Detector	Liquid in String	0.06
"	Gas in String	0.20

TABLE 2 -SINGLE-PHASE CALCULATION OF GAS FLOW RATE

BHP = 3000 PSI

Perforations 7770 -- 7790 1 hole/ft.

Normalizing Factor = 1 for N_{1000HZ}

	MV	N_{1000HZ}	$5(N_{1000HZ}-6)$	$(\bar{q})$Cu.ft./day	(q)Scf/day	
1-	13	13	35	14	2968	
2-	17.5	Same	57.5	23	4876	
3-	18.0	"	60	24	5088	
4-	22	"	80	32	6784	
5-	17.5	"	57.5	23	4876	
6-	17.5	"	57.5	23	4876	42%
7-	17.5	"	57.5	23	4876	
8-	17.5	"	57.5	23	4876	
9-	17.5	"	57.5	23	4876	
10-	17.5	"	57.5	23	4876	
11-	17.5	"	57.5	23	4876	
					53848	
		7824 -- 7832				
12-	16	Same	50	20	4240	
13-	15.5	"	47.5	19	4028	
14-	16.0	"	50	20	4240	
15-	15.5	"	47.5	19	4028	33%
16-	21.0	"	75	30	6360	
17-	21.0	"	75	30	6360	
18-	22.5	"	82.5	33	6996	
19-	20.0	"	70	28	5936	
					42188	
		7855 -- 7874				
20-	13.5	Same	37.5	15	3180	
21-	13.5	"	37.5	15	3180	
22-	18.0	"	60.0	24	5088	
23-	15.5	"	47.5	19	4028	
24-	16.0	"	50	20	4240	25%
25-	15.0	"	45	18	3816	
26-	13.5	"	37.5	15	3180	
27-	11.5	"	27.5	11	2332	
28-	11.5	"	27.5	11	2332	
					31376	
				TOTAL	127412	

FIELD EXAMPLES

Type 1

These are producing wells with channels or communication behind cemented casing.

Figure 4 is a log from a triple, multiple, tubingless-completed oil well. There are multiple channel problems behind the casing from 6000 ft to the bottom. The data were taken in the 2-7/8 in. string on the right, while all three strings are shut-in. The three sets of perforations have anomalies where all four curves show differential pressure and flow. With the reservoir pressure information, it is possible to predict direction of flow. Proving the direction of flow isn't necessary to show there is communication from 7200 ft to 8400 ft. Almost every sand in this interval is taking or making fluid. The peaks on all four curves at 7620 ft indicate there is flow behind the casing past the short string shoe. There is a loss of fluid coupling at 7200 ft. There was not sufficient space to show the interval above 7200

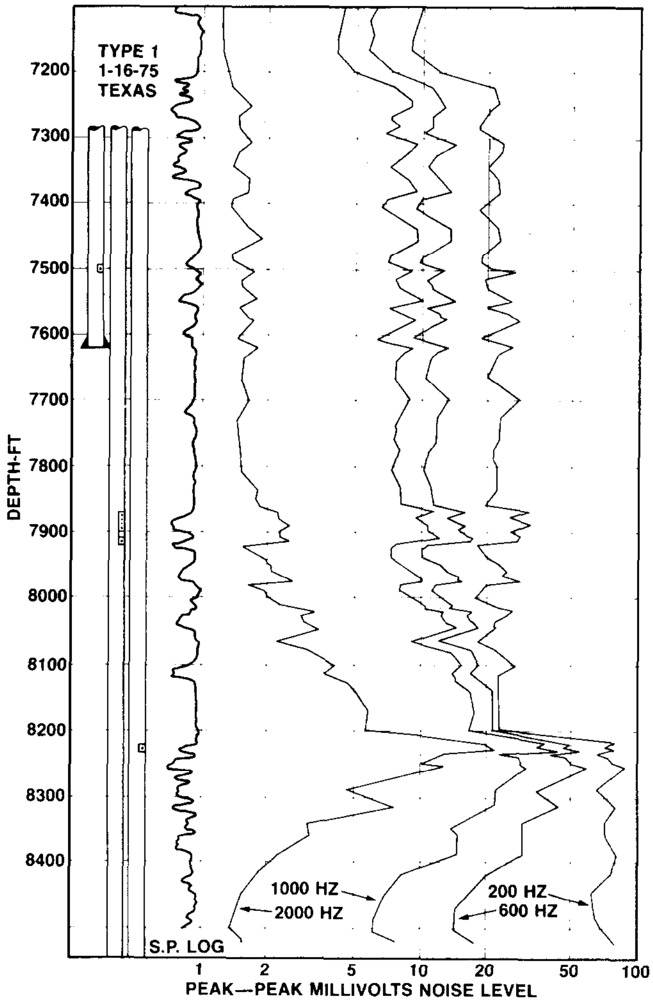

FIG. 4 -TRIPLE COMPLETION PRODUCING WITH MULTIPLE CHANNEL PROBLEMS.

ft. There is flow through the entire interval 7200 ft to 8400 ft and the interval above 7200 ft up to 6000 ft. It is interesting that above the fluid coupling effect at 7200 ft, the 2000 Hz frequency loses coupling, but the other frequencies display similar variations as shown on the log. Above 6000 ft, all four curves drop down to four closely spaced "dead well" curves.

Type 2

These wells have been cemented, and developed channels before perforating or after squeezing.

Figure 5 contains data from a well in Waller County, Texas. The 7-5/8 in. casing was set to 8300 ft and a 5-in. hanger to 10,800 ft. The top of the cement is around 4500 ft. Log 1 was run on September 14, 1973 before the well was perforated for production. All of the porous formations shown on this neutron log are gas sands. The log shows a long interval of high noise level that could not be a result of sound carrying down the hole from just one source. Beginning at the highest peak and going downhole, the noise level decreases and any obvious increase will be an indication of another source of flow through a restriction. Either of these two former conclusions mean flow through an interval or communication. The flow pattern through this interval will be dependent upon the pressure differential between reservoirs. These formation pressures are known and the remedial action has been under study for several years. The program for this well included a squeeze job in two places (A) 6520 ft and (B) 6650 ft on September 20, 1973. Log 2 was run two days after squeezing. As expected, the log shows the cement job for the reservoirs above 6650 ft is in good condition; however, the lower interval of communication, obscured by the loud noise level from 6650 ft, is still present. A second squeeze job was done September 24, 1973 at 6730 ft and 7175 ft.

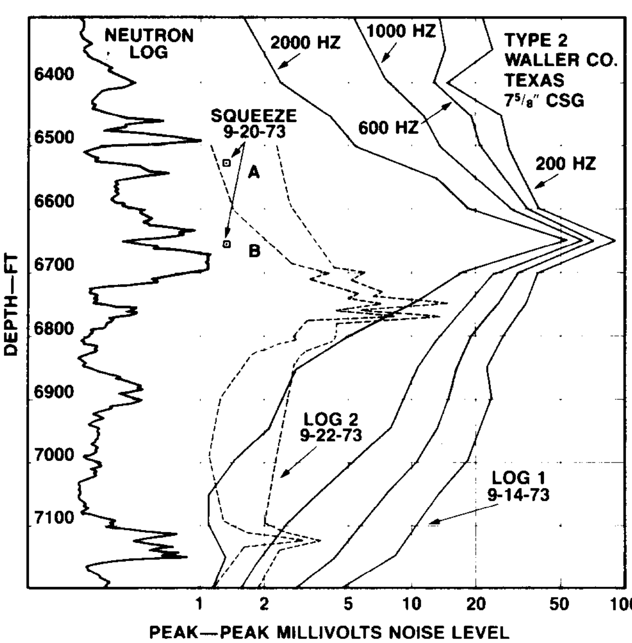

FIG. 5—CROSS FLOW OF GAS BEHIND CEMENTED CASING IN A NEW WELL WITHOUT PERFORATIONS.

Figure 6 (the same well as Fig. 5) shows log 3 which was run September 27, three days after the second squeeze job. Comparing log 3 to the previous log 2, it is apparent that the channels between the lower reservoirs had been cemented off.

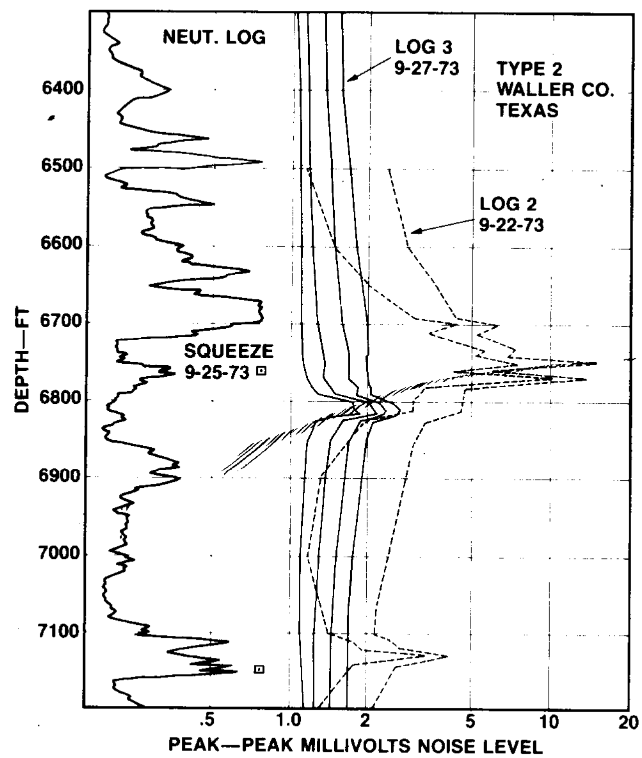

FIG. 6—SAME WELL AS FIG. 5 AFTER A SECOND SQUEEZE JOB.

Type 3

These are problem wells with a recent history of an underground "blowout".

Figure 7 is a log from a drilling well in Louisiana. The 7-5/8 in. casing was cemented below the bit position shown in the figure. A high-pressure water sand was encountered near 17,000 ft while drilling through the 7-5/8 in. casing and the drill string was pulled up until the bit was just above the 7-5/8 in. shoe. The interpretation of the Noise log is that the flow is single-phase coming up behind the 7-5/8 in. and into various sands below 12,000 ft. Flow inside the 7-5/8 in. casing and behind the drill pipe would not show the extreme peaks or character and would show extreme peaks at the hole where the fluid would be leaving the 7-5/8 in. casing. An estimate of the water flow rate was made using the wellhead pressure and the mud hydrostatic to determine the abnormal BHP. The difference between the abnormal and the hydrostatic pressure is used for the differential pressure.

Example: WHP = 2500 psi
12.0 lb mud in the well
Estimated abnormal pressure = 2500 + (0.626) (17,000 ft) = 13,142 psi
Shale zone restriction at 14,800 ft
Water hydrostatic (0.433) (14,800 in.) = 6408 psi

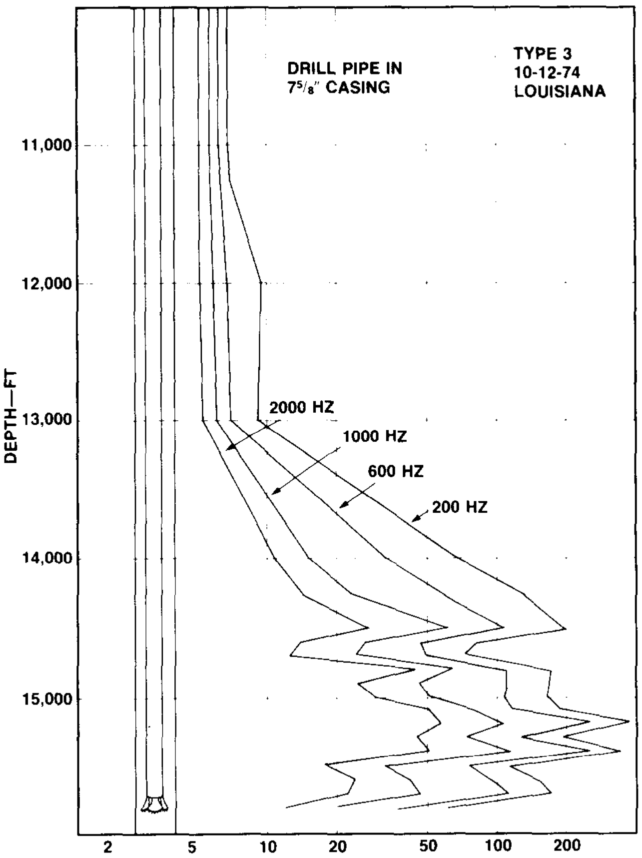

FIG. 7 UNDERGROUND LIQUID CROSS FLOW IN A WELL BEING DRILLED IN LOUISIANA.

ΔP = 13,142 - 6408 = 6734 psi

Noise level of 1000 Hz curve at 14,800 ft = 60 mv

60 (2.5) (2.5) (2) = 750 mv

MV T_f L_f W_g

5 (750 - 6) = (3720 MCFD) (ΔP)

The differential pressure from the source is dissipated in five places as shown by the five sets of peaks.

$$\Delta P = \frac{6734}{5} = 1345 \text{ psi}$$

$$\frac{3720}{1345} = 2.8 \text{ MCFD}$$

$$\frac{2800}{5.6} = 493 \text{ BWPD, flowing}$$

Type 4

These are wells associated with injection.

Figure 8 is a log run with the logging tool in the long string of tubing. The first data were recorded with the well shut-in to obtain a base log. Run 2 data were recorded as water was injected at 800 psi into the 2-3/8 in. x 7-in. annulus and allowed to flow out at the surface through the long string. The log shows a leak at the tie back, packer, and a slight amount at 6950 ft. The operator was only interested in the leak

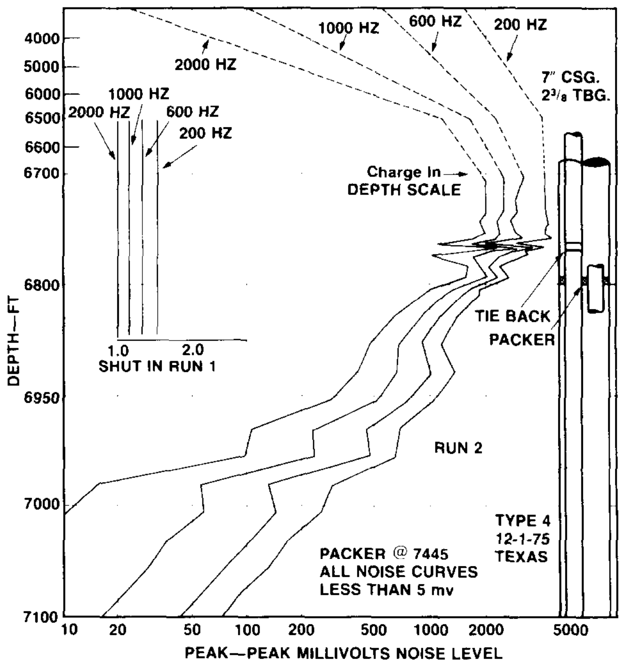

FIG. 8 PUMPING WATER INTO 2-3/8" × 7" ANNULUS AT 800 PSI AND FLOWING LONG STRING OF 2-3/8". NOISE TOOL IN LONG STRING TO LOCATE LEAK.

at the tie back above the packer. The string of tubing was pulled, and the interpretation was verified.

Type 6

These are wells with multiple perforations. The Noise log may be used to determine the relative flow from these perforations.

Figure 9 is a log run in 7-in. casing to determine which zones were producing gas. The three sets of perforations were shot one hole per foot. The flow is mostly single-phase as indicated by the relatively close spacing of the four curves. The peaks appear on all four curves opposite the perforated zones. Using these two conclusions, single-phase flow rate calculations are used. In the top 20 ft of perforations the Noise log indicates eleven holes producing. In the center 8 ft there are eight shots, and in the bottom 19 ft, only nine shots are producing. Table 2 lists the flow rate from each zone.

Figure 10 is a log that was run to determine which of the perforations were producing and to obtain an estimate of each flow rate. On the left side, a 3-1/2 in. casing is shown with 29 single-hole perforations. Beginning at the top, assume that the perforations are numbered 1 through 29. Table 3 contains the interpretation of this log. The well was flowing through a choke, and the estimated total flow rate was 1 MMCFD. One other point of interest is the interpretation of a liquid level near 5460 ft. Observe the relative separation of the 200 Hz from the 600 Hz curve in a depth interval below 3460 ft, as compared to the interval above this depth.

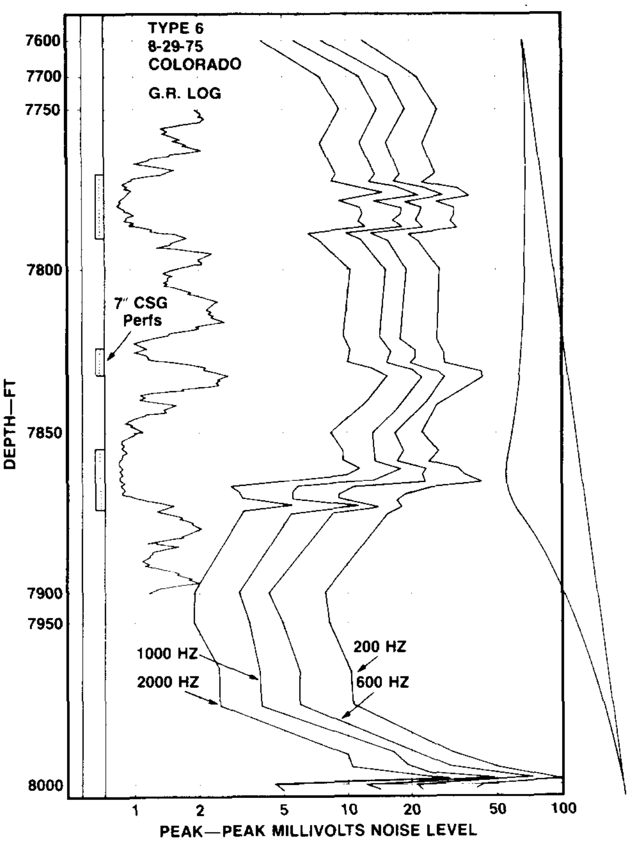

FIG. 9 LOG SHOWING WHICH ZONE PRODUCES GAS AND ESTIMATE OF THE RATE. ALSO A CHANNEL FROM 8000′.

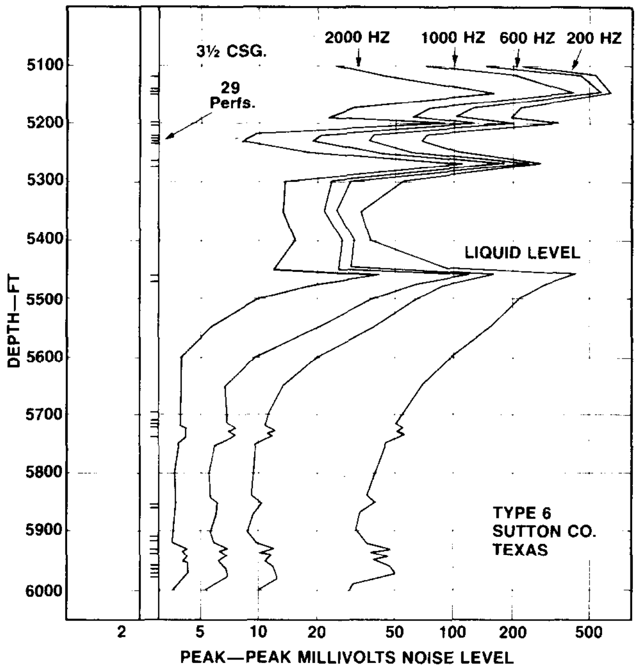

FIG. 10 LOG SHOWING GAS PRODUCTION FROM 29 SINGLE HOLE PERFORATIONS.

TABLE 3—SINGLE-PHASE CALCULATIONS FOR GAS FLOW RATE

Assume BHP = 2500 PSI WHP = 730 PSI

ΔP = 2500 - 930 = 1570

N.F.	Depth	MV(Log)	N_{1000HZ}	$5(N_{1000HZ}-6)$	$(\bar{q})$Cu.ft/day	(q)Scf/day
.75 Gas	1- 5120	213	160	769	512	87,586
	2- 5165	392	294	1440	960	164,160
	3- 5168	448	336	1650	1100	188,000
	4- 5171	392	294	1440	960	164,000
	5- 5198	118	89	415	277	47,400
	6- 5202	118	89	415	277	47,400
	7- 5215	0				
	8- 5220	0				
	9- 5231	0				
	10- 5237	0				
	11- 5258	196	147	705	470	80,370
	12- 5283	196	147	705	470	80,370
.23 Water	13- 5455	123	28	110	73	12,500
	14- 5476	64	15	45	30	5,100
	15- 5692	0				
	16- 5714	0				
	17- 5717	0				
	18- 5725	7.6	1.75	9	6	1,000
	19- 5742	7	1.6	8	5.3	1,000
	20- 5841	6	1.4	7	4.7	1,000
	21- 5847	6	1.4	7	4.7	1,000
	22- 5927	6	1.4	7	4.7	1,000
	23- 5934	7	1.6	8	5.3	1,000
	24- 5946	8	1.85	9.3	6	1,000
	25- 5957	8	1.85	9.3	6	1,000
	26- 5970	0				
	27- 5972	0				
	28- 5978	6.5	1.5	7.5	5	1,000
	29- 5990	6.5	1.5	7.5	5	1,000

Figure 11 is a log run to determine which perforations were producing and the flow rates.

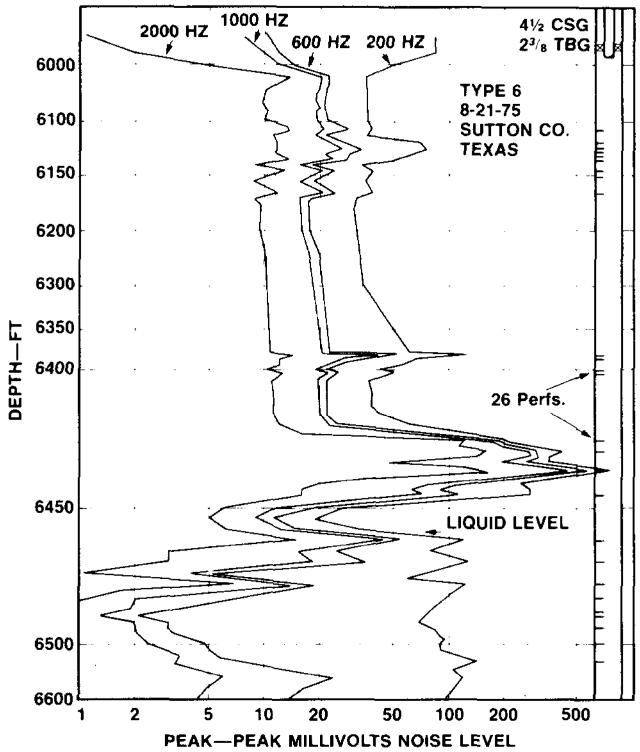

FIG. 11 LOG SHOWING GAS PRODUCTION FROM 26 SINGLE HOLE PERFORATIONS.

Table 4 lists the results of the interpretation. There is a liquid level indicated at 6460 ft.

Figure 12 is a section of log run to determine which sets of perforations were producing and the flow rates. Due to water production, a shut-in log

TABLE 4 -SINGLE-PHASE CALCULATIONS FOR GAS FLOW RATE

BHP = 2500 PSI ΔP = 1500

N.F.	Depth	MV(Log	N_{1000HZ}	$5N_{1000HZ}-6$	($\bar{q}$)Cu.ft/day	(q)Scf/day
1	1- 6107	20	20	70	46.6	7,970
Gas	2- 6120	27	27	105	70	11,970
	3- 6124	25	25	95	63	10,773
	4- 6130	0				
	5- 6127	0				
	6- 6132	24	24	90	60	10,260
	7- 614[illegible]	21	21	75	50	8,550
	8- 6150	21	21	75	50	8,550
	9- 6165	21	21	75	50	8,550
	10- 6373	45	45	195	130	22,220
	11- 6380	26	26	100	67	11,457
	12- 6401	22	22	80	53	9,060
	13- 6402	22	22	80	53	9,060
	14- 6426	200	200	970	646	110,466
	15- 6430	280	280	1370	913	156,125
	16- 6436	470	470	2320	1547	264,540
	17- 6445	78	78	360	240	41,000
Water	18- 6462	45	15	195	130	22,200
.3	19- 6470	18	6	60	40	6,840
	20- 6478	15	5	55	37	6,300
	21- 6483	2	0	8	5	900
	22- 6488	2	0	8	5	900
	23- 6490	2	0	8	5	900
	24- 6494	2	0	8	5	900
	25- 6500	4	1	16	10	1,800
	26- 6530	6	2	24	16	2,800

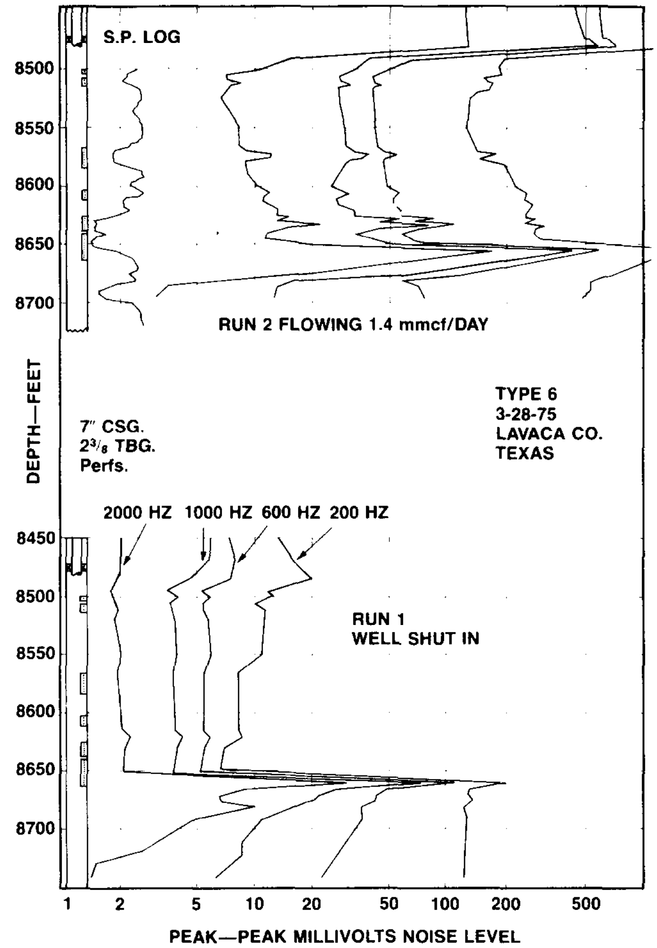

FIG. 12 LOG FROM A WELL WITH SHUT-IN AND FLOWING DATA TO DETERMINE WHICH ZONES ARE PRODUCING GAS.

was run to look for channels. During run 2, the well was flowing gas at 1.4 MMCFD with 400 psi wellhead pressure. Data were taken at two-foot intervals across the perforated zone; however, individual holes in the casing do not show peaks on the four noise curves. The water in the casing causes the sound to be additive. Where the flow is more two-phase than single-phase, the two-phase calculations, shown in Table 5, are necessary.

There are two comparisons that illustrate several important facts. One is comparing one log interval with another on the same run or well conditions. The other is to compare run 1 with run 2 over the same depth interval or at the same depth.

The results from these comparisons are in the following list.

TABLE 5—TWO-PHASE GAS AND WATER CALCULATIONS

Normalizing Factor .23 (Water in borehole)

Sound is additive in water as shown by peaks or lack of peaks. Selecting the peaks on all four curves gives the following results:

	N_{200}-N_{600}	$\frac{N_{2-6}-10}{20}$	(q) mcf/day	(q)Scf/day
8503-05	145	33.4	1.2	80,000
8509-13	120	28	.9	62,000
8567-80	120	28	.9	62,000
8612-18	200	46	1.8	124,000
8626-36	200	46	1.8	124,000
	180	41	1.6	110,000
	200	46	1.8	124,000
8641-60	700	160	7.5	510,000
	700	160	7.5	510,000
			TOTAL	1,700,000

Assumed Bottom Hole Flowing Pressure - 800 PSI

Shut-In Run 1

1. The bottom interval, 8660 ft down, exhibits much wider separation between all curves, especially the 200 and 600 Hz.
2. The noise level is higher on all four curves on the bottom interval.

The separation indicates two-phase flow and to substantiate this fact, liquid coupling enables the flowing sound energy to reach the detector resulting in higher noise level.

3. There is a peak on the 2000 Hz curve below the lowest set of perforations. There is sand at this same depth of 8680 - 8700 ft shown on the SP log.
4. All four curves exhibit an inflection for this sand at 8680 - 8700 ft.

The conclusion from all four observations is that water coming from the sand at 8680 ft is flowing into the gas zone at 8650 ft during the shut-in run.

Figure 13 is a log run to determine which set of perforations was producing gas. The well was flowing 4 MMCFD and should have been producing much more. It is apparent that the perforations at "A" are producing very little gas. The calculations in Table 6 illustrate the quantity of gas from both sets of perforations. The well was reperforated at "A" and the gas production was increased to 12 MMCFD.

Figure 14 is a log from a gas well in Sutton County, Texas. The 3-1/2 in. casing was cemented

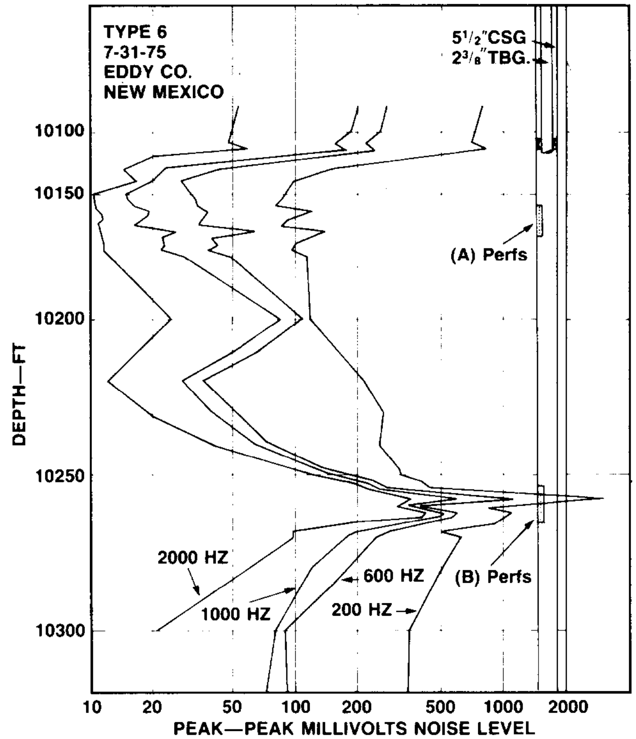

FIG. 13—LOG RUN TO DETERMINE WHICH ZONE IS PRODUCING GAS. ZONE "A" WAS REPERFORATED AND THE PRODUCTION TRIPLED.

to approximately 6000 ft. The perforations in this well were single holes. This 600-ft interval, including many stops one-foot apart, was run in 3-1/2 hours of logging time. Considering the tremendous noise

TABLE 6—SINGLE-PHASE CALCULATION OF GAS FLOW RATE

WHP = 800 PSI P = 3000 PSI

Normalizing Factor = 1 Holes selected from Log Defl.

Perforations 10254 -- 10266

MV	$5(N_{1000HZ}-6)$	($\bar{q}$) Cu.ft/day	(q)Scf/day
230	1120	373	112,000
230	1120	373	112,000
230	1120	373	112,000
230	1120	373	112,000
600	2970	990	297,000
600	2970	990	297,000
510	2520	840	252,000
510	2520	840	252,000
500	2470	823	247,000
500	2470	823	247,000
520	2570	856	257,000
520	2570	856	257,000

10164 -- 10174

MV	$5N_{1000HZ}-6$	($\bar{q}$) Cu.ft/day	(q)Scf/day
20	70	23	6,900
20	70	23	6,900
27	105	35	10,500
25	95	32	9,600
23	85	28	8,400
			42,300

level from gas flowing by the tool, there is good resolution of the sources from the individual perforations. The calculated flow rates from the 1000 Hz curve are shown on the log.

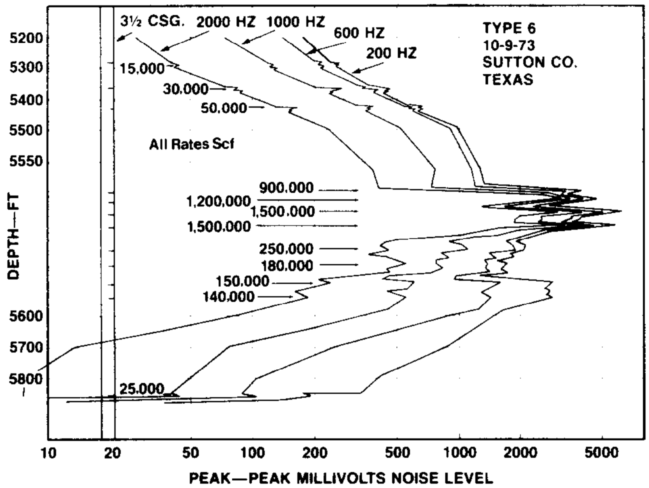

FIG. 14—LOG TO DETERMINE WHICH ZONE WAS PRODUCING GAS AND SHOWING THE RESOLUTION OF THE NOISE AT PERFORATIONS CLOSE TOGETHER.

Figure 15 is a log from a gas well in Colorado County, Texas. The 7-in. casing was set below 8300 ft, with 2-3/8 in. tubing at 7973 ft. The relative flow rates are shown in the figure. A liquid level, well geometry effect is noted on the log which shows the difference in sound coupling due to water being in one interval and gas in the interval above. The bottom set of perforations were supposed to be squeezed.

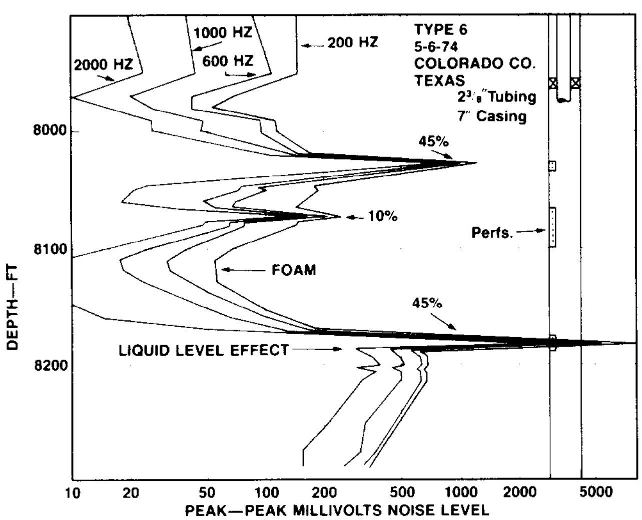

FIG. 15 LOG RUN TO DETERMINE WHICH ZONE WAS PRODUCING GAS.

Figure 16 is a Noise log run in an open hole in Edwards County, Texas. Points of interest, besides the flow rates, are as follows:

1. Repeatability of the log shown at 2730 ft
2. Two-phase flow indicated over the bottom interval and single-phase above the fluid level at 2700 ft
3. The correlation of the Noise log with other formation logs.

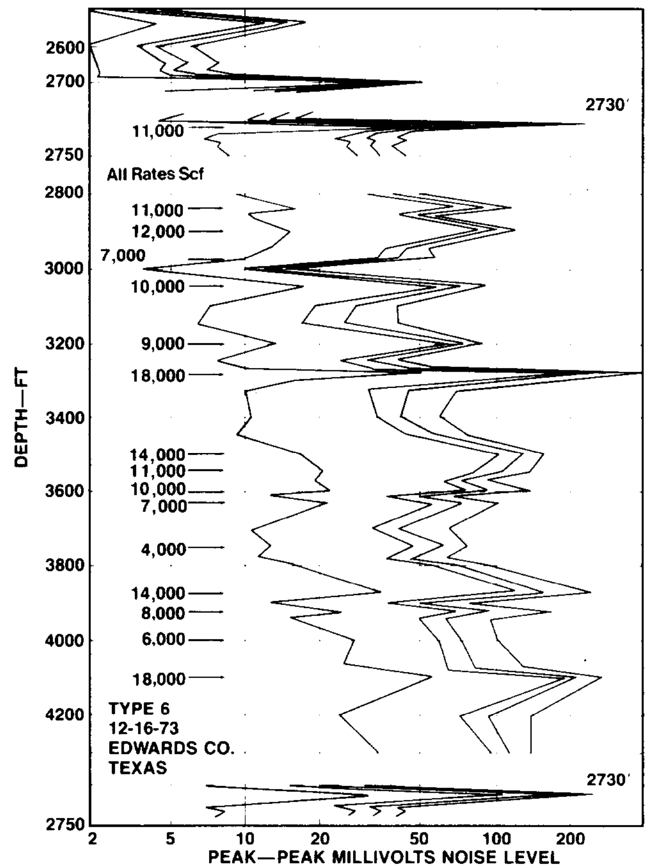

FIG. 16—LOG RUN TO DETERMINE WHICH ZONE WAS PRODUCING GAS. IT ALSO ILLUSTRATES SINGLE PHASE VS TWO PHASE NOISE AND THE REPEAT CAPABILITIES.

Figure 17 is a log from a gas well in McMullen County, Texas, which had 4-1/2 in. casing cemented to 6289 ft, and tubing set to 6088 ft. The Noise log was run to determine which of two sands located six feet apart was producing gas. The upper sand had been squeezed-off two years before, and a radioactive tracer log verified the bottom sand was producing gas. The Noise log showed gas coming from the upper sand. An estimate of the flow rate is shown on the log. To resolve the sound sources, data were taken every foot over the interval of the two sands as the well produced. This is an illustration of the source being located in the interval of high noise level. It is also apparent that 20 ft from the source in either direction, a noise source is being approached. Seeing these changes 20 ft away permits a closer station inspection to locate a source.

CONCLUSION

New information has been obtained as a result of experience from many new well conditions. It is the purpose of this paper to present problems associated with wells in all parts of the country with the idea that this logging technique would be given a broad examination.

BIBLIOGRAPHY

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ACKNOWLEDGMENT

The courtesy of the oil companies, who released log data for the illustration of this paper, is appreciated by the author.

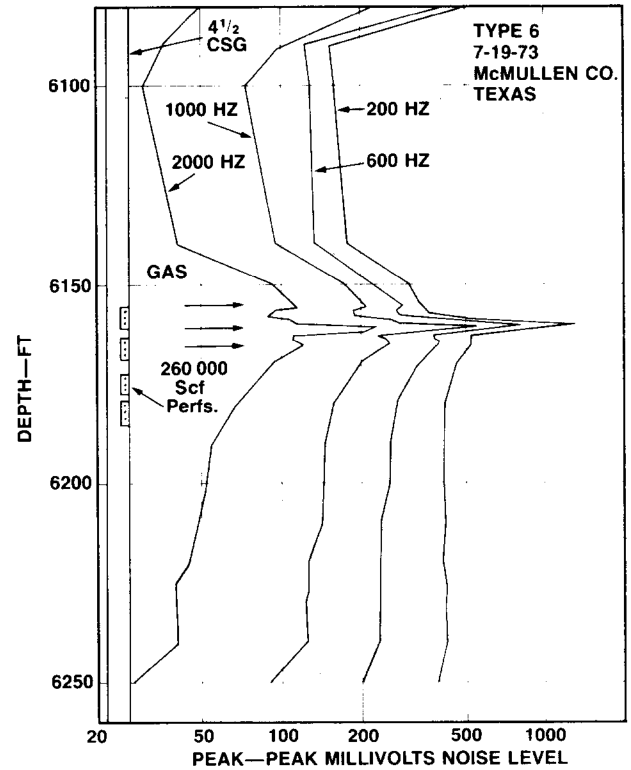

FIG. 17 -LOG RUN TO DETERMINE WHICH OF TWO SANDS WAS PRODUCING GAS AND TO ESTIMATE THE RATE OF FLOW.