A PRIMER ON RADIOACTIVE TRACER INJECTION PROFILING

by
Gunter J. Lichtenberger
Sun Production Company

INTRODUCTION

In secondary or tertiary recovery projects fluids are injected into the rock formations to sweep residual hydrocarbons to producing wells. To optimize this operation the fluids must be injected at specified rates into the desired depth intervals. Therefore, injection profiles are run to determine the injection rates as a function of depth. Although temperature and noise logs can provide some qualitative data, spinner surveys or radioactive (abbreviated r/a) tracer logs are run if quantitative results are desired. At the present time by far the most popular method in use is the downhole radioactive tracer ejection method. The objective of this paper is to review the basic principles underlying this technique.

TOOL DESCRIPTION

In the downhole r/a tracer ejection method, a small quantity of a short lived r/a material, dissolved in an appropriate carrier, is ejected downhole into the fluids flowing in the tubing or casing. As we shall discuss later, the transport and distribution of the r/a tracer, as monitored by gamma ray (γ-ray) detectors, can then be interpreted to yield the desired injection rates as a function of depth.

A schematic diagram of the r/a tracer tool is shown in Fig. 1. Its diameter is about 1 3/8", with a length of about 30 ft. The length of the tool depends on the number of sinker bars required to overcome the upward forces on the cable due to wellhead pressure where the cable enters the well through the 'lubricator' or 'stuffing box'. A complete tool assembly usually comprises a magnetic casing collar locator for depth reference near the top of the assembly, a thermistor probe at the very bottom, one or two γ-ray detectors, and a tracer ejection tool near the middle. The relative position of the tracer ejector and the γ-ray detector(s) may be varied to suit the task at hand, with one or two detectors downstream of the ejector.

Prior to entering the well, the tool reservoir chamber is filled with a solution of radioactive material which can then be ejected, under surface control, through a capillary orifice into the well fluids.

The material commonly used as a tracer is a solution of a radioactive iodine compound in an appropriate solvent to assure proper dissolution in the well fluid. Typical examples would be sodium iodide in water for water injection, methyl or ethyl iodide for gas injection. The iodine isotope acting as the tracer is ${}_{53}I^{131}$ (atomic weight 131, atomic number is 53) which has a half life of about 8.1 days and decays to stable Xenon, ${}_{56}Xe^{131}$, through the emission of five beta particles (i.e., electrons) and six γ-ray photons of various energies (Evans, 1955[1]). The beta particles are absorbed relatively quickly by the surrounding media, and it is the γ-rays that are detected by the logging tool using a Geiger Müller tube or a scintillation counter. A detailed discussion of these detectors is beyond the scope of this paper, but suffice it to say that the Geiger Müller tube is less sensitive to the γ-rays than the scintillation counter, but shows better temperature stability and therefore is more widely used. In either case the γ-rays are converted to 'disintegrations per unit time' or 'counts per second' using suitable electronics. For large counting rates the counting rate of the Geiger Müller tube must be corrected for 'dead time' of the tube[1,2], a fact which is frequently ignored by the contractors. This correction is negligible below about 300 counts/second, but becomes more and more significant for higher counting rates.

The direction of the emission of the γ-rays from the disintegrating iodine atoms is completely random and therefore we can consider the γ-ray flux to be uniform in all directions. Since the half life of 8.1 days is much longer than the time required for a survey (say 3-4 hours), the γ-ray level in a tracer slug is constant for a given tracer concentration.

Only a fraction of the total radiation emitted, however, is registered by the Geiger Müller counter. As for all radiation, the intensity is dependent on the "inverse square law", which is based purely on geometric arguments and states that the number of γ-rays incident on the detector varies inversely as the square of the distance from the source. In addition, the γ-rays are scattered and absorbed by the surrounding media, such as the water, the formation and the tool. These scattering and absorption processes are difficult to analyze quantitatively because of the variety of nuclear reactions that can be involved, depending on the original energy of the γ-ray, and the degree to which it has been absorbed[1].

This, together with our lack of detailed knowledge about the flow mechanism and tracer distribution in the wellbore, makes it very difficult to model or predict quantitatively the response of the tool to a slug of r/a material. Full scale tests[3] have shown that the number of disintegrations per second recorded by the detector is proportional to the amount of tracer material nearby, and the detector output will "map" the slug. It must be kept in mind, however, that this mapping is not perfect because of the appreciable range of the γ-rays, which may approach 1-2 ft. Thus, the detector output will be proportional to some average tracer concentration in the vicinity of the tool.

THE TRACER LOSS LOG

Data Acquisition

After running a depth correlation γ-ray log and cross-correlating casing collars with those from a wellbore diagram to ascertain proper depth readings, the strip chart recorder is put into "depth drive" where the paper advance is directly coupled to the depth indicator. With the tool well above the zones of anticipated fluid loss, but at least about 30 ft below the packer or tubing end, a small quantity of r/a material is ejected from the tool, with the well injecting at the desired surface rate. At low injection rates, some operators prefer to mix the tracer into the wellbore fluids by moving the tool up and down a few times. Then the tool is lowered below the slug, and moving upwards at a rate of about 1-2 ft/sec the counting rate from one of the detectors is plotted on the strip chart to produce a tracer concentration profile along the slug. When the counting rate reaches a maximum, "zero time" is recorded. The profile obtained should be nearly bell shaped or triangular, and not more than 30 ft long. After traversing the slug, the tool is quickly lowered and brought up again through the slug to map its new size, shape and location. Again the time at which the maximum counting rate occurs is recorded: the elapsed time together with the displacement of the slug peak can be processed to yield first order estimates for the slug velocities, which in turn can yield an injection profile as discussed in the paragraphs on velocity shots. This procedure is repeated several times until the slug shows zero velocity over a time span of 15-20 minutes, or has virtually disappeared. A set of traces similar to those shown in Fig. 2 should be obtained.

Data Interpretation

The Area Method

To establish a method for the interpretation of the tracer loss log, let us subdivide the concentration profile of a tracer slug into a large number of elements of width Δw_n over which we can consider the tracer concentration in the slug to be uniform and equal to C_n. If the cross sectional area of the wellbore at that depth point is X_n and if we assume that C_n is uniform across X_n, then the total quantity Q of tracer material in the slug is

$$Q = \sum_{slug} X_n \Delta w_n C_n \quad , \ldots\ldots\ldots (1)$$

If the time interval required to run the log is short compared with the half life of the tracer, then the quantity of tracer material Q_i in the initial slug is equal to the amount L_{ij} of tracer material lost to the formation plus the amount Q_j of tracer still in the wellbore below the zone of fluid loss, so that

$$Q_i = L_{ij} + Q_j \quad , \ldots\ldots\ldots (2)$$

We also reiterate the assumption that the detector output R_n is approximately proportional to the tracer concentration.

$$R_n = (1/_b)\ C_n, \ldots\ldots\ldots (3)$$

Where b is a proportionality constant which relates the concentration to the strip chart pen deflection. We can then write

$$Q_i = b \sum_{slug} R_i\ \Delta w_i = b\ A_i \quad \ldots\ldots (4)$$

Summing all the elements $R_i \Delta w_i$ over the depth interval of the slug is equivalent to finding the area A_i under the graph of a tracer slug, so that

$$Q_i = b\ A_i \ldots\ldots\ldots\ldots (5)$$

Similarly, below the zone of tracer loss

$$Q_j = b \sum_{slug} R_j\ \Delta w_j = b\ A_j \quad \ldots\ldots (6)$$

so that

$$\frac{Q_i}{Q_j} = \frac{A_i}{A_j} \quad \ldots\ldots\ldots\ldots (7)$$

i.e., the fraction Q_i/Q_j of tracer left in the wellbore is proportional to the ratio A_i/A_j of the areas under the graphs recorded while traversing the slugs.

We now must relate the behavior of the tracer material to that of the injection fluid.

This is perhaps best illustrated with Fig. 3. Here a single tracer slug element travels along a rectangular duct of unit cross section. At point d_0 the slug element width is w, it travels with a velocity u and its concentration is C_0. At d_1 this element is divided by a very thin wall, and 40% of the slug is diverted out through a "perforation". To conform with reality, the duct is restored to its full cross section at d_3. Because the total volume of the element cannot change at this point, its length is shortened by 40%, while the concentration remains at C_0. And thus, as derived previously, the change in area under the concentration profile is a measure of the fluid loss. Other elements, without tracer, can be expected to behave in exactly the same way so that the tracer and the fluid will behave identically.

We know from experience, however, that the peak concentration of a slug decreases as it travels down the wellbore, while its length increases. This is mostly due to eddy diffusion caused by the turbulence in the fluid which will continuously dilute the leading and trailing edges of the slug and eventually erode the maximum concentration at the center. It is this process which yields the bell shaped concentration profiles. The previous reasoning can be extended to cover this case as well: instead of a single slug element we now monitor an array of adjacent elements, each of a different concentration going past the perforation as shown in Fig. 4. If we make the distance d_0d_3 small, the overall length of the slug will be reduced by 40% because each element was reduced 40%; and again the concentration of each element will remain the same because d_0d_3 is too short an interval for appreciable mixing to occur. Subsequent mixing will redistribute the tracer over a longer slug, but the term $\Sigma X_j \Delta w_j C_j$, and therefore A_j, will remain the same. Only if the perforation itself segregates the tracer from the fluid, by a filtration process for example, the above interpretation technique can be expected to break down.

Accuracy

We have shown that the relative fluid loss through a perforation can be obtained from area measurements of the γ-ray detector output. But it is equally important to know at what depth this fluid loss takes place. The difficulties associated with depth resolution can be discussed by reference to Fig. 5. Suppose we know approximately where the fluid loss is taking place and we run tracer concentration profiles above and below it so that the profiles do not overlap. Following current industry practice, the area values A_1 and A_2 are assigned to the point of maximum tracer concentration at d_1 and d_2, respectively. The fluid loss is then assigned to the interval d_1d_2, while in reality it was only a single perforation. Moving the traces closer together improves the depth resolution until the profiles touch at the base line. Further reduction in d_1d_2 may help the depth resolution, but now only part of the slug has traversed the perforation. Because only the shaded elements of the slug in Fig. 5 which have traversed the zone of fluid loss are reduced in width, the total area A_2' will be larger than A_2 and the fluid loss will be underestimated. In reality, of course, we do not know, a priori, where the fluid leaves the wellbore and any, or all of the traces, except the initial one(s), may straddle those zones. It becomes readily apparent that the best results can be expected for a narrow r/a tracer slug where nearly non-overlapping concentration profiles can be mapped only a few feet apart. Generally speaking though, the tracer loss log is likely to be a semi-quantitative tool which will reveal zones of major fluid loss, but which will yield only approximate quantitative estimates for the injection rates as a function of depth.

Data Presentation

One method of listing and processing tracer loss log data is shown in Table 1. Here the entries were derived from the traces of Fig. 2: after filling in the base line for each tracer, the area under each one was found (in arbitrary units) using a planimeter. The current industry practice of drawing tangents to the inflection on the skirts of the tracer and evaluating the area of the resulting triangle (RST or R'S'T' in Fig. 5) formed with the base line may be satisfactory for nearly bell shaped plots, but is likely to yield poor results when the traces are more irregular.

Setting area A_0 under the first trace equal to 100%, the percentage of fluid left in the wellbore derived from subsequent trace areas A_j is given by 100 (A_j/A_0). Subtracting these values from 100% gives the total percentage of loss; the interval loss is the incremental change in the percentage of loss between table entries. As mentioned before, the areas are assigned to the depth value of the tracer maximum, and the fluid loss intervals are the depth intervals between these maxima. The percentage loss per ft, i.e., the ratio of the percentage of interval loss divided by the interval length is usually a better indicator for narrow zones of major fluid loss (or thief zones).

The right hand part of the table lists the slug velocity data. Knowing the travel time and displacement distance of the trace maxima, the slug velocities are evaluated. As will be discussed later, for a uniform flow diameter the transit velocity is a measure of the amount of r/a material, or fluid, in the hole. The percentage of tracer in the hole is given by 100 (u_j/u_0). Where u_0 is the reference fluid velocity above the zones of fluid loss, and the u_j's are the velocities measured at other depth points. The total percentage of loss and interval loss are derived as before; but here the percentage of the tracer in the hole is assigned to the midpoint between trace maxima, and the intervals are the depth differences between them.

Figs. 6 and 7 show histogram plots of the injection profile calculated in Table 1. Without the aid of the velocity shot data, it would be difficult to decide if any significant injection was occurring above about 3900 ft, but the tracer loss log results indicate substantial fluid loss between 3895 and 3980 ft, with a possible thief zone between 3950 and 3975 ft.

Applications

From the above discussion we can deduce that the tracer loss log method is not affected by sandface injection rate variations because the fluid velocity does not enter the analysis. Furthermore, distortions of the slug elements such as might be caused by diameter variations in the wellbore only result in a redistribution of the tracer material, but do not affect the overall area under the concentration profile. Thus, the log is well suited for open hole completions, serves as backup data in case difficulties are encountered with the velocity shots, and at the time of the survey it gives the logging engineer an overview of where fluid loss is taking place. Difficulties may be encountered in polymer injection projects because the slug length may become excessive due to the high viscosity of the fluid and retention of r/a traces on the wellbore walls.

THE FLUID VELOCITY LOG

Data Acquisition

The objective of the fluid velocity log is to determine the injectivity profile from changes in the fluid velocity which are associated with fluid loss from the wellbore: working from the bottom upwards, the tool is positioned at the desired depth and a small quantity of r/a tracer material is injected. The passage of the r/a slug is then monitored by the two detectors and recorded on the strip chart, with the recorder set to "time drive" where the strip chart speed is calibrated in terms of inches per second. Traces similar to those shown in Fig. 8 are obtained. The transit time between detectors is then read off the strip chart between equivalent points on the two traces. Choosing the peaks of the two tracers as reference points often leads to poor accuracy because they may be ill defined; in most cases using the point of first arrival will yield the best results.

Data Interpretation

The Transit Time Method

As fluid leaves the wellbore, the volumetric throughput through the wellbore decreases by an equivalent amount with increasing depth. Thus the volumetric velocity u (or mass transport velocity) must decrease proportionately: if u_0 is the reference velocity at d_0 above the zones of fluid loss, corresponding to the surface injection rate Q_0, then the flow rate Q_j in the wellbore at any depth point d_j is $Q_j = 100\ Q_0(u_0/u_j)$ where u_j is the velocity measured at d_j. If the wellbore diameter is non-uniform, the velocities u_j can be corrected by multiplying them by a factor $(D_j^2-D_t^2)/D_0^2-D_t^2)$ where D_0 and D_j are the wellbore diameters at d_0 and d_j, respectively, and D_t is the tool diameter. Or, by accounting for all units the flow rate Q (BPD) for a volumetric velocity u (in/sec) is

$$Q = 6.995(D_j^2-D_t^2)u \quad . \ . \ . \ . \ . \ . \ . \ . (8)$$

Unfortunately, the velocity measured by the above method is not necessarily equal to the volumetric throughput velocity u. Due to viscous drag along the walls the velocity profile across any conductor is non-uniform. A thorough discussion of this subject is beyond the scope of this paper, but suffice it to say that the fluid velocity is zero near the walls and reaches a maximum u_{max} somewhere near the midpoint between flow boundaries. The ratio $C = u/u_{max}$ depends on the conductor geometry, and the degree of turbulence. As discussed by Knudsen and Katz[4], for example, the value for C is typically between 0.5 to 0.8 for the range of laminar (i.e., non-turbulent) flow to fully turbulent flow, respectively. Since the degree of turbulence increases with the volumetric throughput, and is larger for smaller flow diameters, the volume of C may be different for each well and will vary with depth as fluid is lost to the formation.

Since the fluid stream displays localized velocities which range from zero to u/C, different parts of the slug will travel at different velocities and the meaning of a transit time can become ambiguous. The solution to the problem is to ensure that tracer material enters the fastest streamlines, and then "first arrival" measurements should yield reproducible results. We can then write

$$Q_j = 6.995(D_j^2-D_t^2)C_j h/\Delta t. \ . \ . \ . \ . \ . \ . (9)$$

where h is the detector spacing in inches and Δt is the first arrival transit time in seconds. C_j will be in the range given above, but can be expected to be near 0.8 when the fluid velocity is measured in the tubing where the flow is likely to be turbulent.

Failure of the tracer to reach the fastest streamline is a frequent source of erratic velocity measurements. It becomes significant particularly when the ejector to first detector spacing is small and fluid velocities are low, so that the tracer may not be mixed into the fastest streamline by turbulent mixing. For this reason it becomes difficult to take velocity shots in highly viscous polymer injection projects; and it is also partially the reason for the greater data scatter from single detector systems where the measured transit time between ejection and first arrival is heavily dependent on the tracer reaching the fastest streamline almost immediately after ejection.

Data Presentation

Table 2 shows a typical data tabulation for velocity shots. The percentage of tracer in the hole was derived from the velocity ratios and the other calculations are identical to those in Table 1. It is important that the surface injection rate be monitored regularly to account for any possible changes in the measured transit times. In addition to the tool dimensions, the operator must note strip chart speeds, sensitivity and time constants as they can affect the appearance of the velocity shots significantly.

The Interval Method

For the velocity shots we determine the transit time of a tracer slug over the detector spacing, which may be typically 5-6 ft, and the resulting velocity is assigned to the midpoint between the detectors. When the tool is opposite a zone of fluid loss, however, the velocity over this interval will not be uniform. Although in many situations this is of no great importance, it may be critical if we are trying to isolate zones only a few feet thick which may be acting as thief zones, for example. In this case velocity shots are taken only a few feet apart and the data is interpreted using the interval method. Here any observed changes in the transit time are associated only with the new depth intervals straddled by the tool from one shot to the next.

This is best illustrated with an example: consider the data set in Table 3 which gives transit times for a detector spacing of 6 ft. The perforations for this case were between the 5026 and 5044 ft level. Thus a velocity measurement for any interval located above the 5026 ft depth would yield a reference velocity. Fig. 9 shows how the values are generally computed from the average transit time values. In Table 4, we have broken down the transit time for the various two-foot intervals. The reference measurement time was 18 seconds, or six seconds per two-foot interval. For the second measurement, the instrument straddled the intervals from 5022 to 5024, 5024 to 5026 and 5026 to 5028 ft. For each of the first two intervals the transit time must still be six seconds because they are above the perforations. So the transit time for the 5026 to 5028 ft interval must be 32 - (6 + 6) = 20 seconds. Similarly, for the interval from 5028 to 5030 ft, the time is 60 - (6 + 20) = 34 seconds. The next measurement covers the interval 5028 to 5034 ft, i.e., the tool was four feet lower than the previous position. Now the transit time from 5028 to 5030 is known to be 36 seconds, and from 5028 to 5036 it is 120 seconds. We assign a transit time of (120 - 34) /2 = 43 seconds to each of the intervals from 5030 to 5032, and 5032 to 5034.

The results of the above interpretation which have been plotted in Fig. 10 show clearly that the interval analysis can give results which are quite different from the averaged data. In many cases this analysis will also show up discrepancies in the data that are not noticeable otherwise, and may help to isolate bad data points. For example, if the interval transit time suddenly decreases below its previous value, something is likely to be wrong with the data point. Possibly a diameter change due to buildup on the casing walls is responsible for this phenomenon because it would result in a higher velocity or a lower transit time. It is possible that fluid first leaves and then re-enters the casing, but this channelling can usually be detected by the r/a tracer technique because the tracer in the channel will move at a different velocity than the fluid in the casing, and give rise to a secondary hump on the tracer log profiles.

Applications

R/A tracer velocity shots can provide reasonably accurate injection profiles if the shot density is high enough and care is taken that the transit times can be read sufficiently well. The velocities are sensitive to the cross section of the well-bore and it may be necessary to run a caliper to ascertain the hole diameter. To improve the statistics on the measurements, and to check repeatability, it may be desirable to take several velocity shots at one depth point. In polymer injection projects the viscous fluids may make it difficult for the traces to reach the fastest streamline and repeatability should be checked at each depth point.

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3. Bearden, William G., Cocanower, R. D., Currens, Dan and Dillingham, Mat: "Interpretation of Injectivity Profiles in Irregular Bore Holes", SPE-2685, presented at the Denver Meeting of SPE, September, 1969.
4. Knudsen, J. O. and Katz, D. L.: "Fluid Dynamics and Heat Transfer", McGraw Hill, 1958.

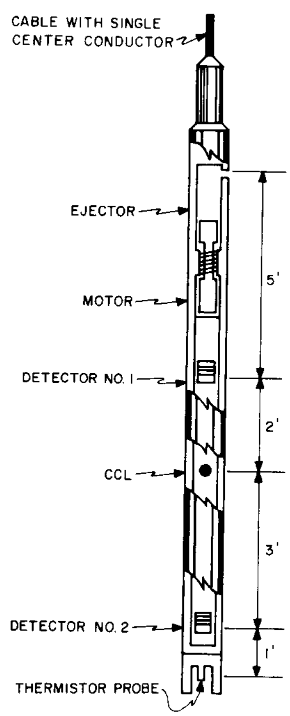

FIGURE 1 — THE RADIOACTIVE TRACER TOOL

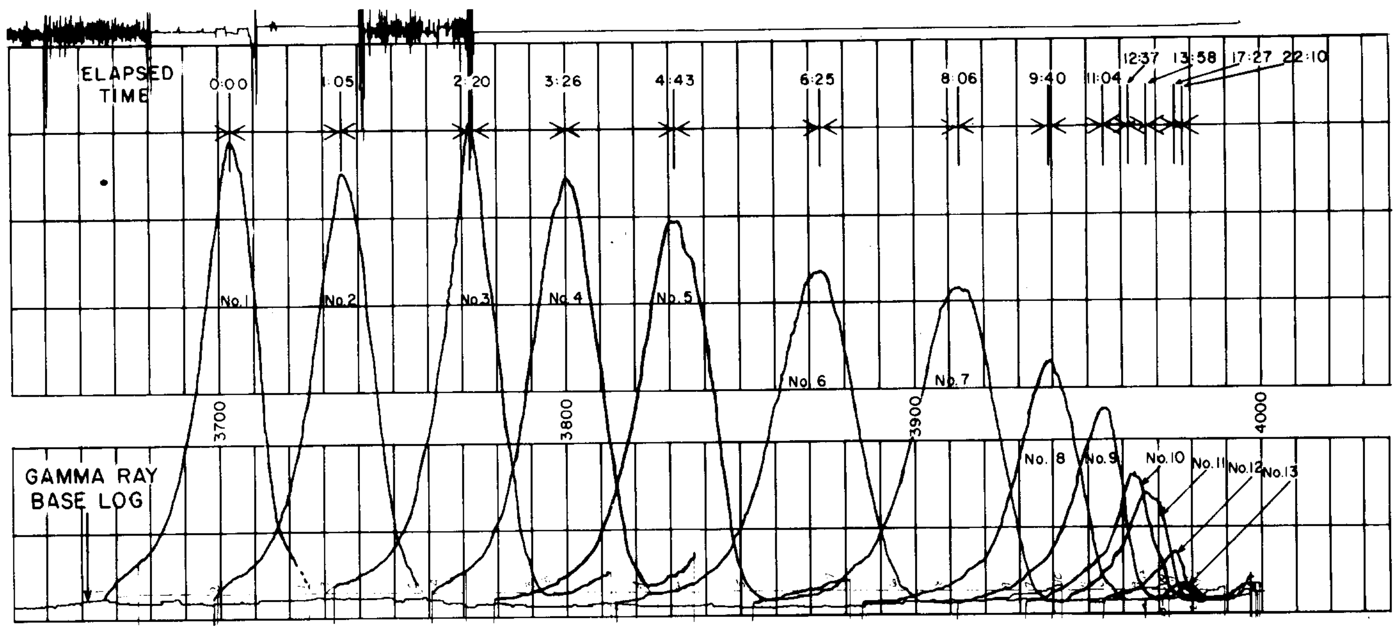

FIGURE 2 — TYPICAL TRACER LOSS LOG TRACES

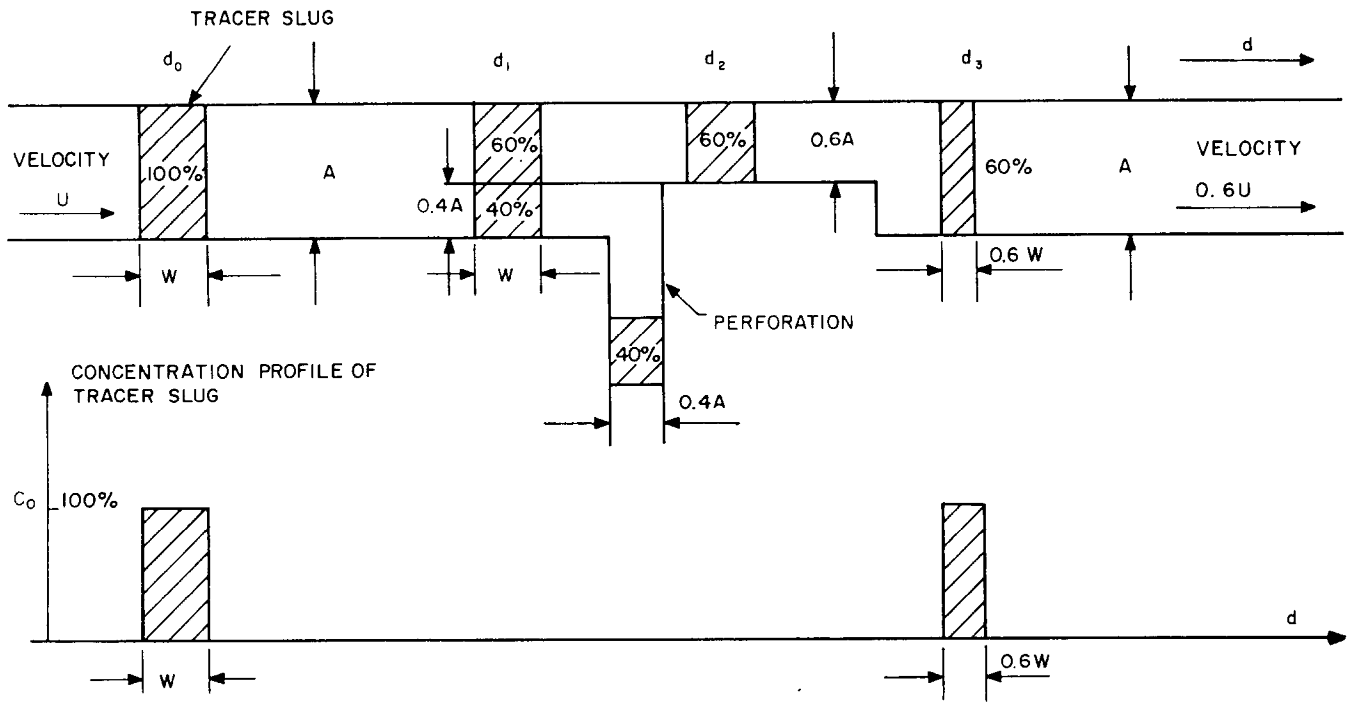

FIGURE 3 — SCHEMATIC ILLUSTRATING THE REDUCTION IN LENGHT OF A TRACER SLUG AS IT PASSES A PERFORATION

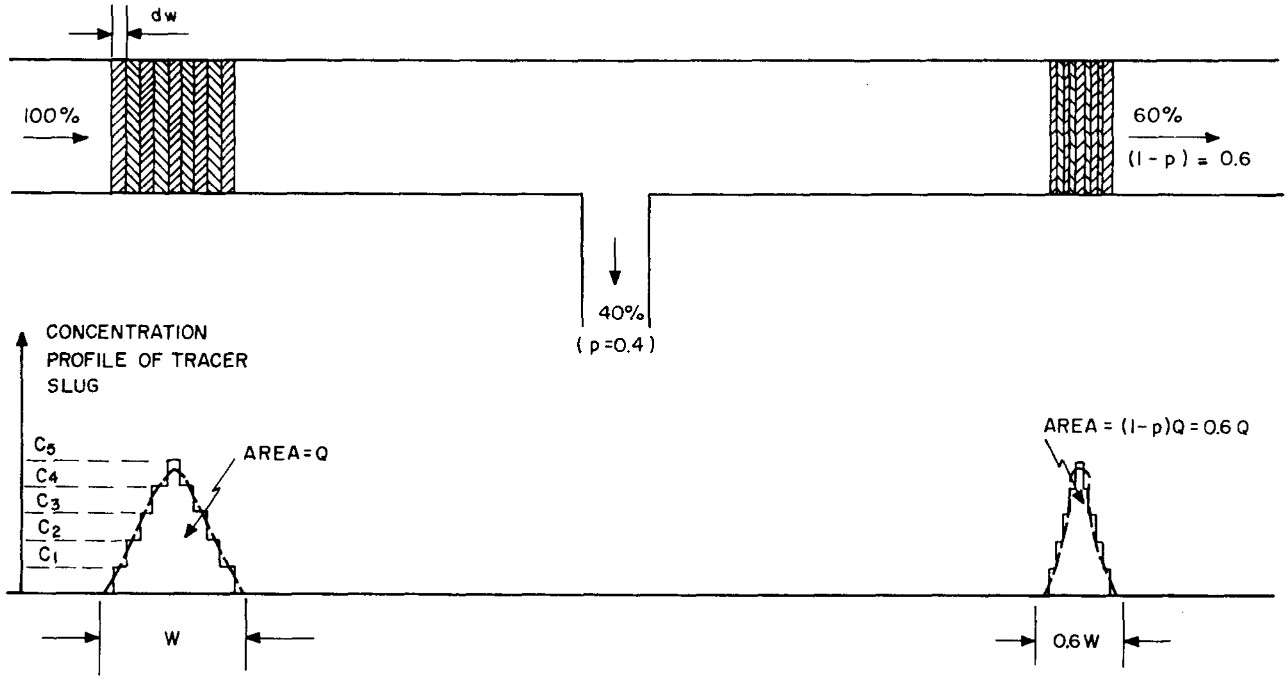

FIGURE 4 — SCHEMATIC SHOWING SYNTHESIS OF A REAL CONCENTRATION PROFILE FROM SLUG ELEMENT OF DIFFERENT TRACER CONCENTRATIONS

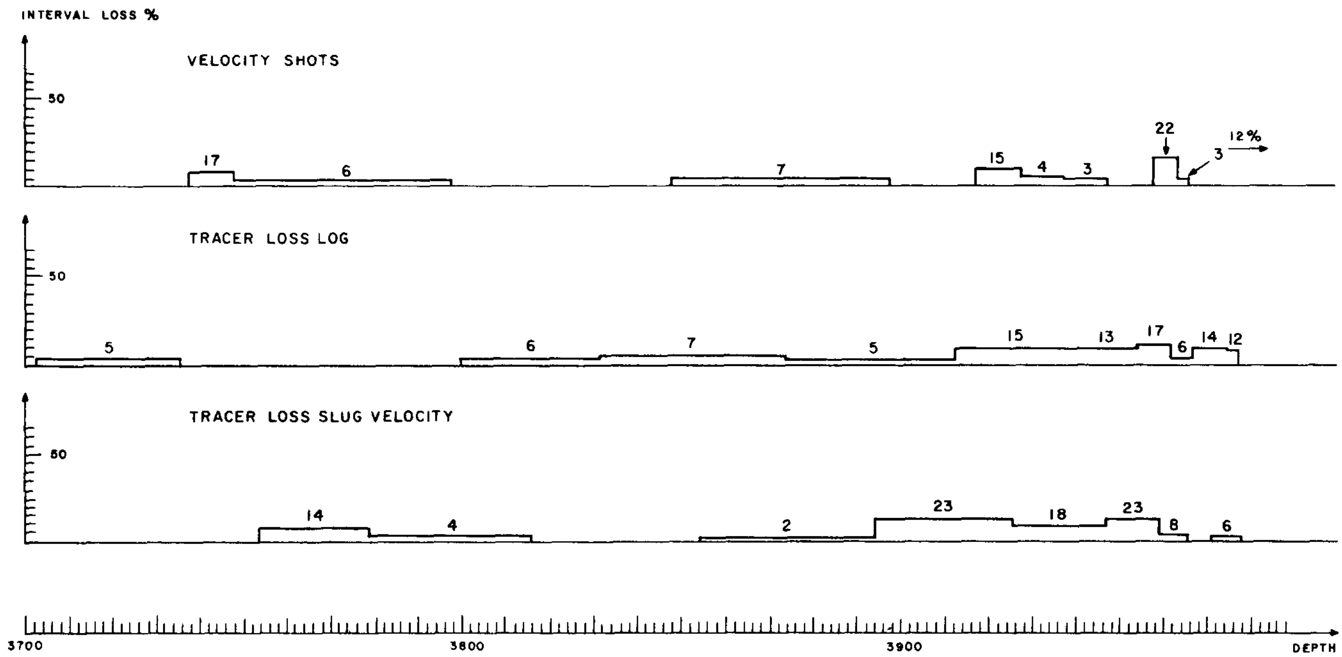

FIGURE 6 — INTERVAL LOSS (FROM DATA IN TABLES 182)

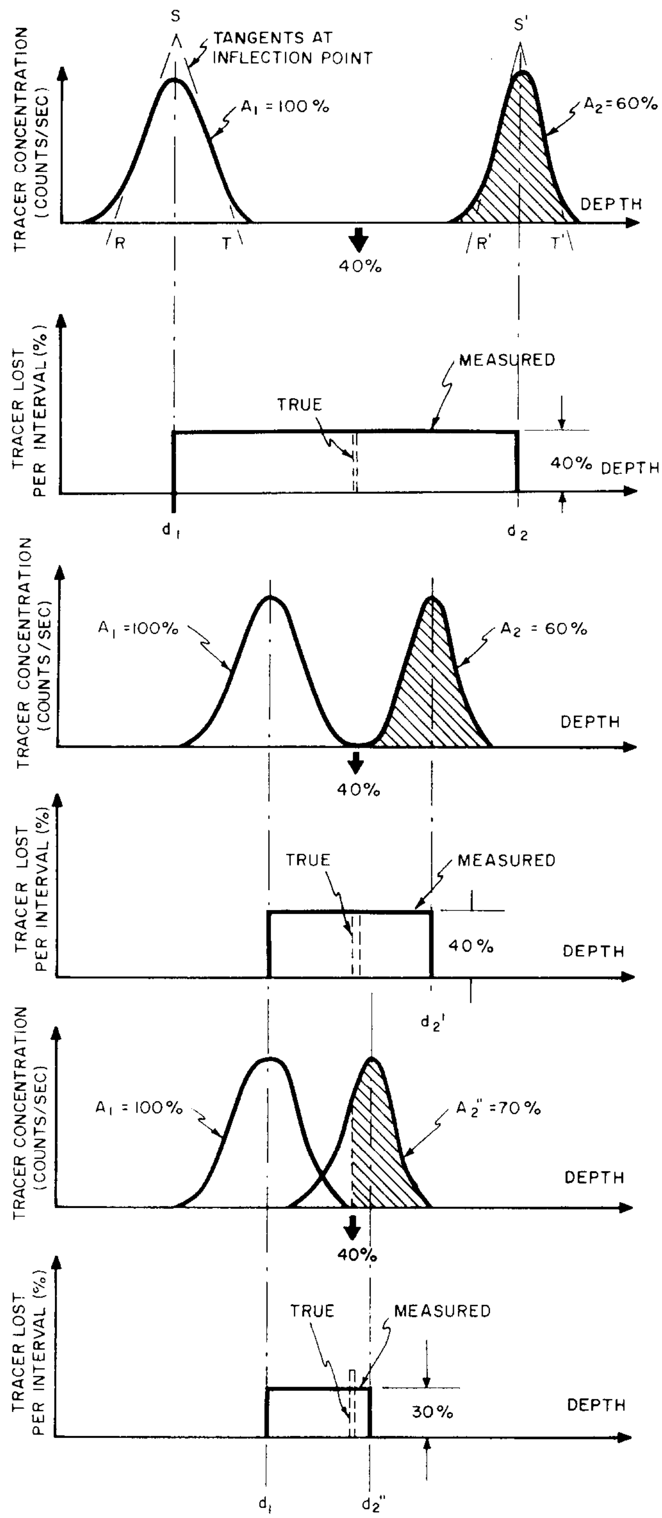

FIGURE 5 — EFFECT OF TRACER PROFILE PROXIMITY ON THE RESULTS FOR THE AREA METHOD FOR FLUID THROUGH A SINGLE PERFORATION

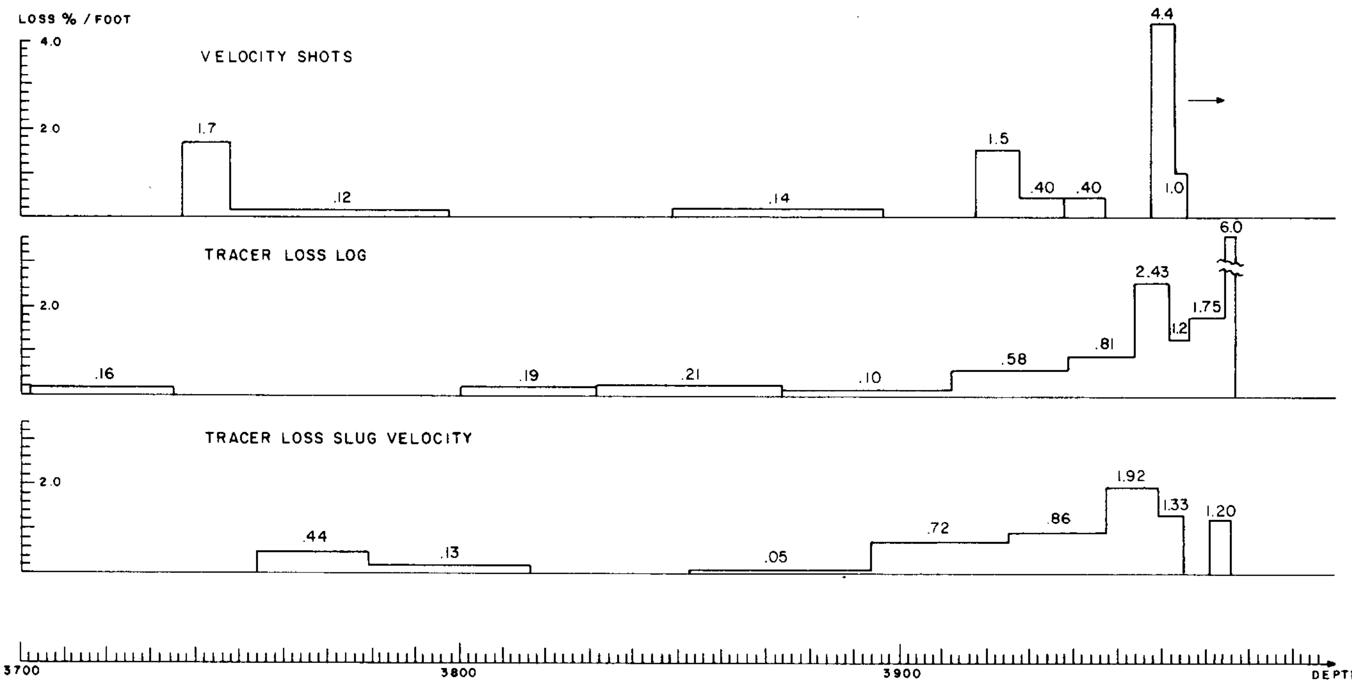

FIGURE 7 — % LOSS PER FOOT (FROM DATA IN TABLE 1 8 2)

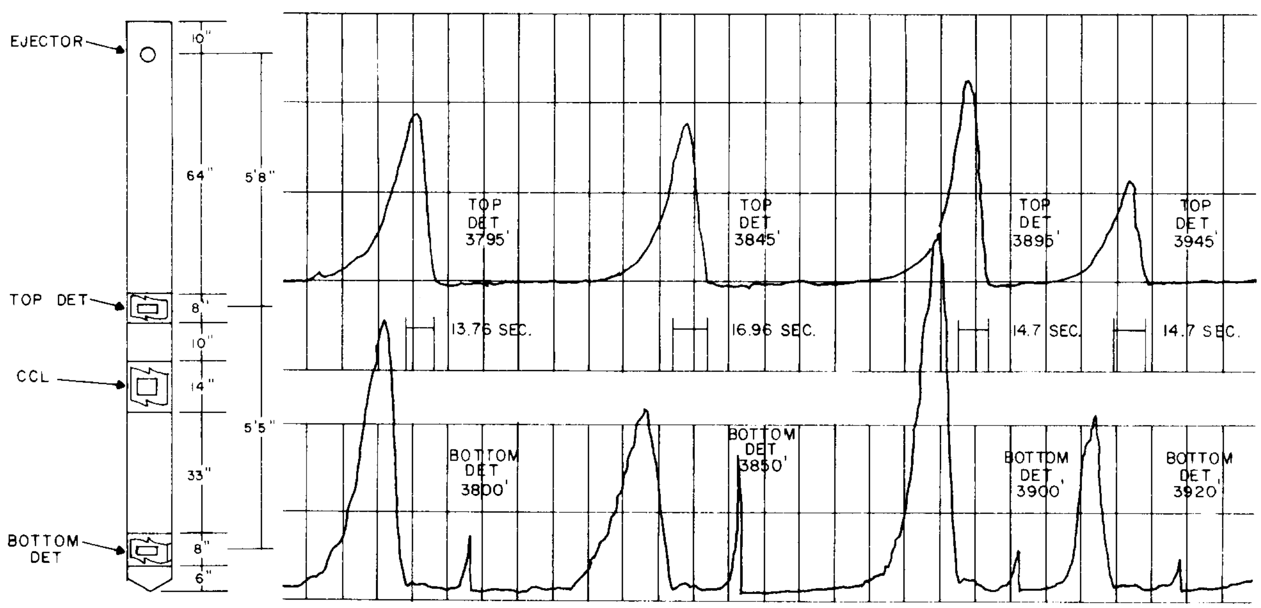

FIGURE 8 — TYPICAL TRACER VELOCITY SHOT TRACES

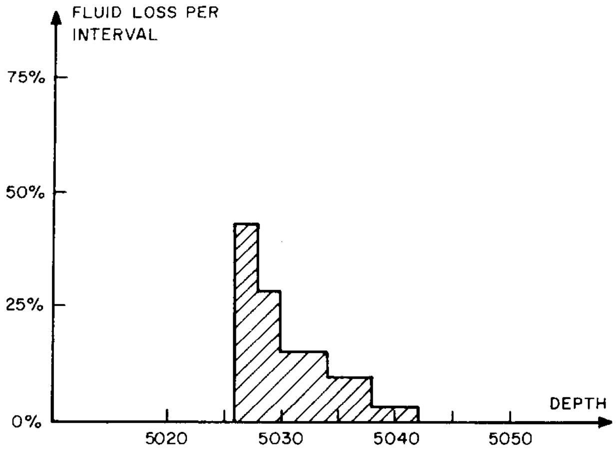

FIGURE 9

INJECTION PROFILE FROM TABLE 3

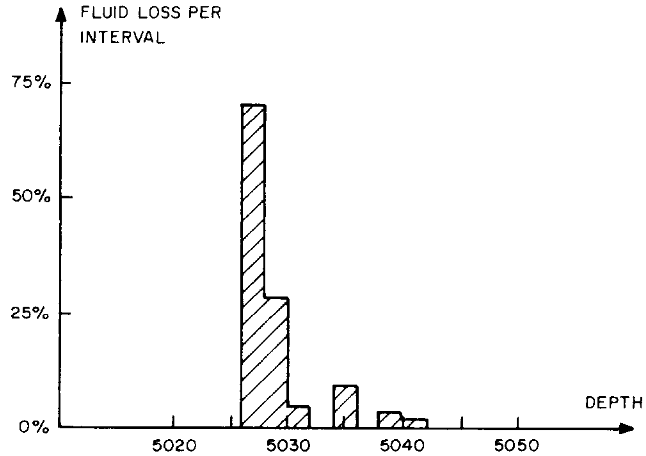

FIGURE 10 — INJECTION PROFILE FROM TABLE 4 (INTERVAL METHODS)

TABLE 1
TRACER LOSS LOG DATA TABULATION

SHOT NO: 1 : TRACER LOSS SURVEY

Notes: Flow Rate prior to Shot No. 1 1555 BPD at 8030 hrs.
Areas measured using a planimeter.

SLUG	DEPTH OF PEAK FT.	AREA	TRACER IN HOLE %	TOTAL LOSS %	INTVL LOSS %	INTVL FT	LOSS/FT. %/FT.	ELAPSED TIME MIN:SEC	TIME/INTVL SEC	DIST. FT	SLUG VELOCITY FT/SEC	I.D. IN	TRACER IN HOLE %	TOTAL LOSS %	INTVL LOSS %	PEAK DEPTH MEAN FT	INTVL. FT	LOSS/FT. %/FT
1	3703	16.25	100	0				0:00				6.46						
					5	32	.16		65	32	.49		100	0		3719		
2	3735	15.50	95	5				1:05				6.46			0		35	0
					0	37	0		75	37	.49		100	0		3754		
3	3772	17.50	95	5				2:20				6.46			14		32	.44
					0	28	0		66	28	.42		86	14		3786		
4	3800	15.50	95	5				3:26				6.46			4		30	.13
					6	31	.19		77	31	.40		82	18		3816		
5	3831	14.50	89	11				4:43				6.46			0		37	0
					7	33	.21		102	43	.42		(86)	18		3853		
6	3874	13.25	82	18				6:25				6.46			2		41	.05
					5	49	.10		101	39	.39		80	20		3894		
7	3913	12.50	77	23				8:06							23		32	.72
					15	26	.58		94	26	.28		57	43		3926		
8	3939	10.00	62	38				9:40				6.46			18		21	.86
					13	16	.81		84	16	.19		39	61		3947		
9	3955	8.00	49	51				11:04				6.46			23		12	1.92
					17	7	2.43		93	7	.08		16	84		3959		
10	3962	5.25	32	68				12:37				6.46			8		6	1.33
					6	5	1.2		141	5	.04		8	92		3965		
11	3967	4.25	26	74				13:58				6.46			0		6	0
					14	8	1.75		209	8	.04		8	92		3971		
12	3975	2.00	12	88				17:27				6.46			6		5	1.2
					12	2	6.0		283	2	.01		2	98		3976		
13	3977	-	0	100				22:10										

TABLE 2
RECOMMENDED DATA PRESENTATION FOR r/a TRACER
VELOCITY SHOTS

TRACER VELOCITY SHOTS												WELL HEAD CHECK		
SHOT #	TOP DET FT.	BTM. DET FT.	TRAVEL TIME SEC.	VELOCITY FT/SEC.	I.D. IN.	TRACER IN HOLE %	TOTAL LOSS %	INTVL LOSS %	MID-POINT FT.	DEPTH INTERVAL FT.	LOSS/FT. %/FT.	TIME OF DAY	FLOW RATE BPD	TUBING PRESSURE PSI
13	3735	3740	10.5	.52	6.46	100	0		3738			1120	1540	
								17		10	1.7			
12	3745	3750	12.8	.43	6.46	83	17		3748					
								6		50	.12			
11	3795	3800	13.7	.40	6.46	77	23		3798					
								0		50	0			
10	3845	3950	16.9	.32	6.46	-	23		3848					
								7		50	.14			
9	3895	3900	14.7	.37	6.46	71	29		3898			1015	1520	
								0		20	0			
8	3915	3920	14.7	.37	6.46	71	29		3918					
								15		10	1.5			
7	3925	3930	19.2	.29	6.46	56	44		3938					
								4		10	.40			
6	3935	3940	26.5	.21	6.46	40	60		3938			0945	1530	
								4		10	.40			
5	3945	3950	28.8	.19	6.46	36	64		3948					
								0		10	0			
4	3955	3960	28.8	.19	6.46	36	64		3958					
								22		5	4.4			
3	3960	3965	65.9	.08	6.46	15	85		3963					
								3		3	1.0			
2	3963	3968	85.1	.06	6.46	12	88		3966					
								0		2	0			
1	3965	3970	99.2	.06	6.46	12	88		3968			0915	1550	

NOTES:

Casing O.D. 7 in.
Shoe 3585 ft.

Tubing O.D. 2.0 in.
Type Plastic
End 3585 ft.

Packer Depth 3585 ft.

Open Hole I.D. 646 in.
From 3585 ft.
To 3998 ft.

Depth Reference: (Top Det) Bott Det.

Sun Flow Rate: 1500 BPD

Tool Diameter 1 in.
Detector/Detector Spacing ft. See Diagram
Ejector/Detector Spacing ft.
Time Constant 3.0 sec.
Sensitivity 2.0

5' Sinker Bar was added between ejector & first detector

(Perforations from 5020 - 5044 ft)

Example (3rd line)

% of fluid in the Conductor = 100 x 18/60 = 30%

% of fluid lost = (100 - 30)% = 70%

% loss in interval 5028 to 5030 = (70 - 43)% = 27%

TABLE 3
EXAMPLE OF
INJECTION PROFILE DATA AND USUAL INTERPRETATION

Depth Interval (ft)	Depth Assigned (ft)	Transit Time (sec)	Total Fluid in Casing %	Total Fluid Lost %	Loss Per Interval %
5020-5026	5026	18	100	0	
					43
5022-5028	5028	32	56	43	
					27
5024-5030	5030	60	30	20	
					15
5028-5034	5034	120	15	85	
					9
5032-5038	5038	300	6	94	
					3
5034-5040	5040	600	3	97	
					3
5036-5042	5042	infinite	0	100	

TABLE 4
INTERVAL ANALYSIS OF DATA IN TABLE 3

Depth (ft)	Transit Time for 2 ft. Interval (sec)						Total Fluid in Conductor %	Total Fluid Lost %	Loss per Interval %
5020									
	6						100	0	0
5022									
	6	6					100	0	0
5024									
	6	6	6				100	0	0
5026	18								
		t=20	20				30	70	70
5028		32							
			t=34	34			18	82	12
5030			60						
				t=43			14	86	4
5032									
				t=43	43		14	86	0
5034				120					
					t=128	128	5	95	9
5036									
					t=129	129	5	95	0
5038					300				
						t=343	2	98	3
5040						600			
							0	100	2
5042									
									100%