Improved Method to Evaluate Steam Quality for Steam Injection Well based on Neutron Albedo Measurement

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The ‘steam injection well’ is a method to recover viscous oil or tar from underground formations by injecting steam into the well to heat the oil. In order to make an efficient recovery for heavy oils, it is necessary to know the quality of steam delivered into the well. The steam quality, the mass fraction of water existing in the steam , inside the well is normally estimated by extrapolating the measured one at the wellhead to the downhole conditions through heat loss calculation on the modeled well, but is not so easy to know the actual situation, in particular at the bottom of the well. It is, therefore, useful to measure the steam quality directly in the downhole because more efficient recovery of heavy oils can be expected through more precise steam driven heat control and management.

The PTD (Pressure-Temperature-Density) tool has been developed for direct measurement of the steam quality in the downhole, consisting of a set of pressure, temperature and density sensors housed in a long tube. The density sensor, called as D probe, utilize neutron albedo to measure the steam density, where a Cf-252 neutron source is located between thermal and epithermal neutron detectors.

In this study, we have devised a new method measuring a near/far ratio, defined as a counting ratio of a near spacing neutron detector to a far spacing one from the neutron source, to improve the measurement accuracy of the D-probe. This paper describes some successful results on the near/far ratio method making corrections to reduce the uncertainties of the steam density measured with the D-probe through Monte Carlo neutron transport simulations and calibration experiments.

Key Words: MCNP, McBend, Near/Far Ratio, oil well logging, PTD tool

1 INTRODUCTION

A proto-type PTD-tool consists of P-probe, T-probe and D-probe, as shown in Figure1. In order to obtain the steam quality in the borehole, the value of steam pressure, temperature and density are required. The pressure is measured by P-probe, and the temperature is measured by the T-probe. The steam density is measured with neutron counts by the D-probe. Use a fast neutron source Cf-252 located between Thermal and Epithermal neutron detectors, as shown Figure2.

In this last study [1], benchmark test had performed using the test tank which was designed to simulate one part of the live steam injection well. After verification test and computer simulations, the filed tests [1] had carried out to verify the fundamental performance of the tool at the steam injection well. The field test had conducted in the Cymric Field (California St.) supported by Chevron U.S.A. Petroleum Company Western Business Unit and Chevron Petroleum Technology Co. However, measured steam quality in the borehole were lower than the calculated results using heat-loss model.

At that time, these errors were considered with the statistical error of Monte Carlo simulation and the error of count rate of the detector. And, error analysis had performed about statistical errors inherent to the Monte Carlo simulation and the counting rate of the detectors. But appropriate results had not got yet, and we were investigated about other causes on second thought.

In oil well logging, detector responses were influenced by conditions of measured area. Those conditions are complicated circumstances behind a lot of matter. A kind of the formation materials and its' thickness, water content in the cementing layer of outer surface of the tubing and its' thickness, equivalent steam density surrounding the D-probe, may be caused to uncertainties for detector count rate. In particular, measured data of water content in the cementing layer and its' thickness are exists, but those data is a log data of just after the end of the well logging. In short, those log data will not be differ from state of around the borehole.

Then, the next D-probe should be redesigned which have no sensitivity against those uncertainties. In this study, we have devised a new method measuring a near/far ratio, defined as a counting ratio of a near spacing neutron detector to a far spacing one from the neutron source, to improve the measurement accuracy of the D-probe.

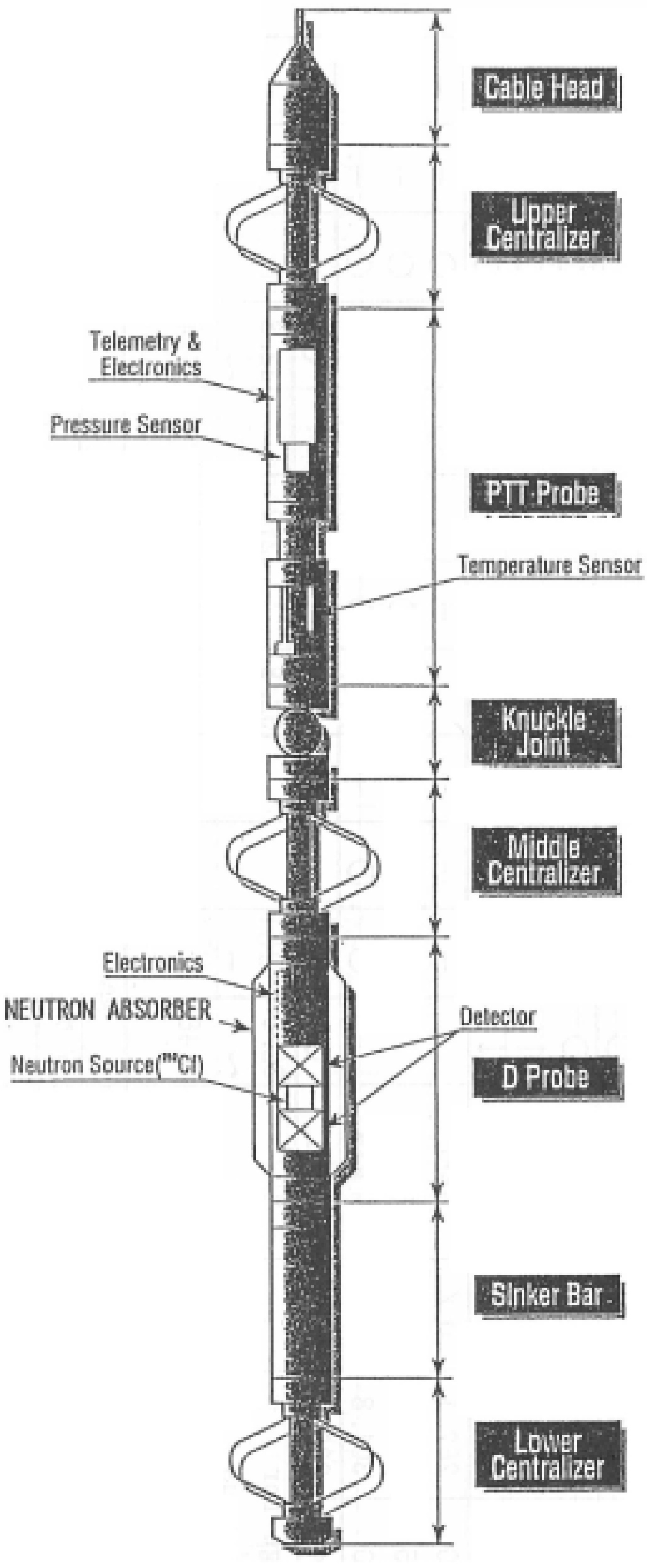

Figure 1. Configuration of PTD Tool

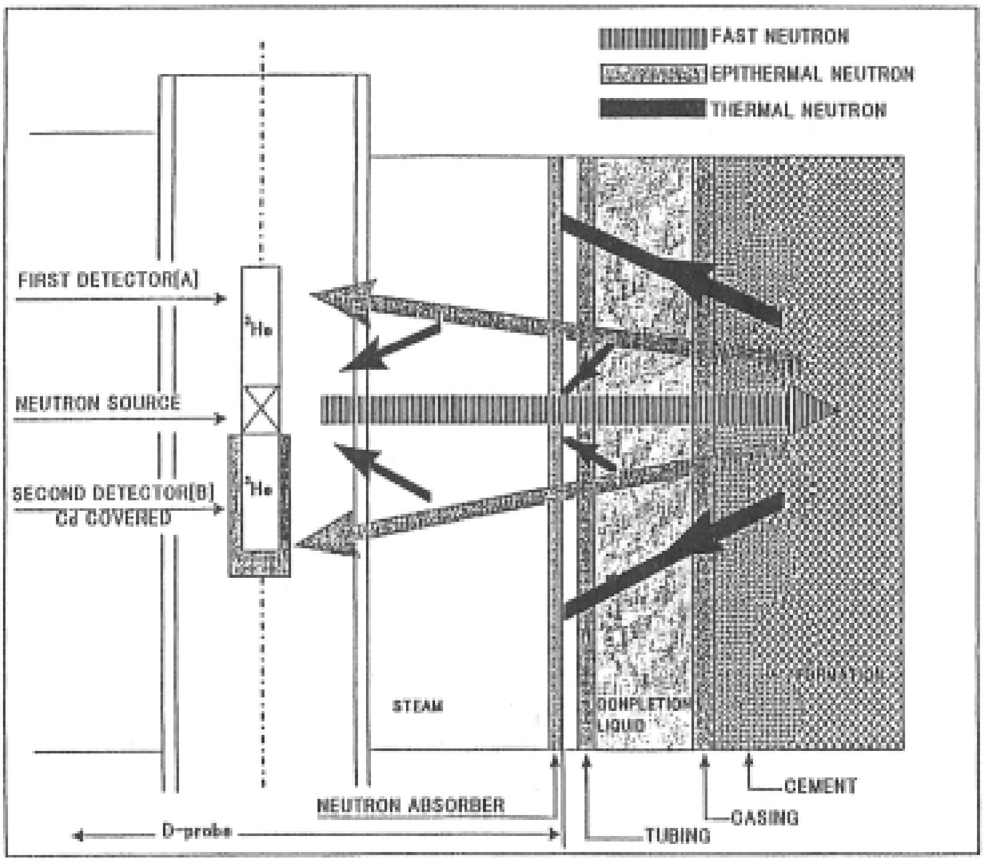

Figure 2. Behavior of Neutrons Around D-Probe

1.1 UNCERTAINTIES

In oil well logging, uncertainties of detector response have a lot of causes, for example, mineral of formation, salinity (concentration of salt in under ground water), distribution condition of natural gas. But, these causes will be come to a settlement by “Log Interpretation”. Log interpretation were performed by log analyst with Log Charts which were made in the last study for long term period.

However, steam injection well is injected steam to secondary product of oil. Then, the conditions of oil field have been changed continually, for example, water content in the cementing layer of outer surface of the borehole and its’ thickness. These fluctuations had been studied for a long time, which is called “Cement Bond Log”.

As a result, near/far ratio was proposed for compensation of slowing down of thermal neutron cause of uncertainties.

1.2 Near/Far Ratio

In general, near/far ratio was used for measurement of formation porosity at the outside of borehole. Slowing down of neutron energy is inversely proportional to the square of the distance from source. Around the borehole, neutron density of near field was dominated by fast or epithermal neutron and it is increase with depending on the formation porosity. However, neutron density of far field was dominated by thermal neutron and it is decrease with depending on the formation porosity. Then, in the intervening period near and far field was called the cross-over zone. Usually, near/far ratio was measured in this far filed. Therefore, the effect of thermal neutron diffusion process will be compensated for detector response.

In this study, we want to measure the steam density in the borehole. In this measurement, detector response was received the effect of the borehole outside. And, we were considered with adoption of near/far ratio method for the removal of effect of the borehole outside from detector response. However, this near/far ratio is not use for measurement of borehole outside, but it is use for not measurement of borehole outside.

1.3 Measurement system of D-probe

As shown in Figure2, the fast neutron emitted by spontaneous fission of Cf-252 penetrate through casing, cementing layer and reservoir formation where the fast neutron slowing down to the epithermal and thermal neutrons due to inelastic and elastic scatterings. A part of these slowing down neutron return back to casing again. Then, only the epithermal neutrons can return back in the steam flow region because the thermal neutrons are almost absorbed by neutron absorber contained Cadmium sheet. As shown in Figure3, originally, Cadmium Ratio [2][3] as defined as follows has been applied to obtain steam density, i.e., Cadmium Ratio = (A-B)/A, where A is the counts of epithermal + thermal neutron and B is the counts of epithermal neutrons. This Cadmium Ratio may be applicable for the case of existing hydrogen rich materials outside the steam flow region, for example, an annulus [4] filled up with completion liquid, but because almost of steam injection wells have never such the annulus system, some uncertainties originated in environmental conditions, ex, quantity of water content in cement and reservoir, have been introduced to the calibration data used on evaluating the steam density.

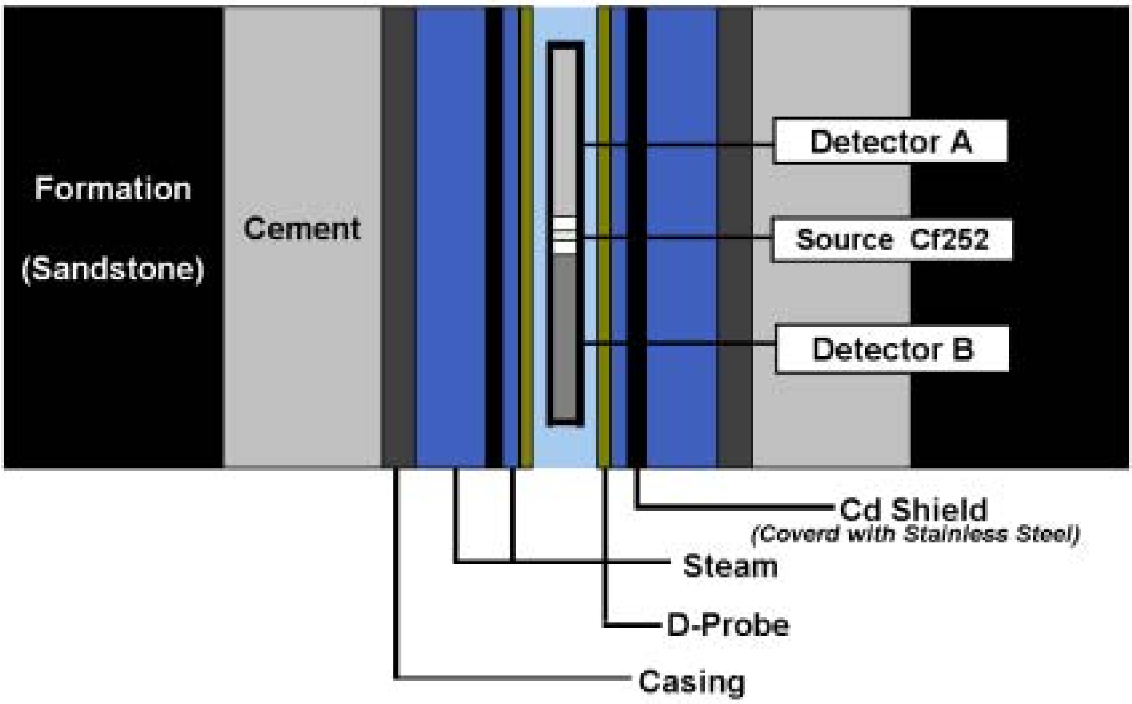

Figure 3. Analyzed Model

1.4 Benchmark Test and Simulations

In order to validate the responses estimated by simulations, benchmark test has been performed using test pit (Figure3), designed to mock up one part of the actual steam injection well. A kind of the formation materials and its' thickness, water content in the cementing layer of outer surface of the casing and its' thickness, equivalent steam density surrounding the D-probe, can be variable by replacing the materials and its' thickness or volume.

Since the early 1980's, Monte Carlo codes to solve radiation transport problems and evaluate the response in nuclear logging tools, have been commonly used. We have analyzed the benchmark test by using MCNP [5] code and obtained the responses, in the last study [1]. In this time, we were recalculation about this benchmark test with McBend [6] code. These have been compared with the measured data as shown in Table Ⅰ.

Almost of McBend C/E ratio are better than MCNP C/E ratio. These main reasons were thought by different of thermal neutron cross section. In this study, we were used JEF-2.2 nuclear library for McBend and ENDF/B-5 nuclear library for MCNP. Rightly, we were considered with S(alpha, beta) effect of MCNP for thermal neutron treatment. But, MCNP C/E ratio are not good in hydrogen rich cases.

Table Ⅰ. Comparison of Calculation and Experimental Results

Detector A

Case No.	Cement Layer		Steam Density	Calculation [C.P.S]		Experiment	Comparison	
	Thickness	Material	[g/cm³]	MCNP	McBend	[C.P.S]	MCNP C/E	McBend C/E
16	2.2 inches	Air	0	102.4	106.3	106.3	0.96	1.00
17	2.2 inches	Air	0.04	106.1	112.4	108.4	0.98	1.04
18	2.2 inches	Air	0.08	109.8	119.7	114	0.96	1.05
19	2.2 inches	Air	0.22	146.7	150.7	139.6	1.05	1.08
3	2.2 inches	Cement Powder	0	108.6	118.1	118.3	0.92	1.00
4	2.2 inches	Cement Powder	0.04	115.9	124.1	125.4	0.92	0.99
5	2.2 inches	Cement Powder	0.08	125.5	133.7	132	0.95	1.01
6	2.2 inches	Cement Powder	0.22	166.5	173.8	170	0.98	1.02
12	2.2 inches	Fresh Water	0	188.2	201.5	225.8	0.83	0.89
13	2.2 inches	Fresh Water	0.04	195.1	209.6	227.8	0.86	0.92
14	2.2 inches	Fresh Water	0.08	205.6	230.6	237	0.87	0.97
15	2.2 inches	Fresh Water	0.22	251.9	270.1	270	0.93	1.00
2	3.2 inches	Air	0	78.7	81.1	86.2	0.91	0.94
7	3.2 inches	Air	0.08	84.7	91.8	97	0.87	0.95
8	3.2 inches	Air	0.22	113.7	116.1	116.2	0.98	1.00
9	3.2 inches	Fresh Water	0	185.3	189.5	213.6	0.87	0.89
10	3.2 inches	Fresh Water	0.08	202.8	207.4	229	0.89	0.91
11	3.2 inches	Fresh Water	0.22	240.1	258.2	261	0.92	0.99
1	-	(Polyethylene)	-	237.4	-	252.2	0.94	-

Detector B

Case No.	Cement Layer		Steam Density	Calculation [C.P.S]		Experiment	Comparison	
	Thickness	Material	[g/cm³]	MCNP	McBend	[C.P.S]	MCNP C/E	McBend C/E
16	2.2 inches	Air	0	88.8	95.5	96.8	0.92	0.99
17	2.2 inches	Air	0.04	90.7	100.2	98.6	0.92	1.02
18	2.2 inches	Air	0.08	93.2	100.3	103	0.90	0.97
19	2.2 inches	Air	0.22	104.7	115.8	118.5	0.88	0.98
3	2.2 inches	Cement Powder	0	96.5	108.4	109.9	0.88	0.99
4	2.2 inches	Cement Powder	0.04	100.7	110.6	113.6	0.89	0.97
5	2.2 inches	Cement Powder	0.08	104.4	113.1	119	0.88	0.95
6	2.2 inches	Cement Powder	0.22	122.6	132.5	144	0.85	0.92
12	2.2 inches	Fresh Water	0	158.1	174.3	196.7	0.80	0.89
13	2.2 inches	Fresh Water	0.04	159.2	179.1	198.9	0.80	0.90
14	2.2 inches	Fresh Water	0.08	163.5	180.1	203	0.81	0.89
15	2.2 inches	Fresh Water	0.22	178.1	194.8	217	0.82	0.90
2	3.2 inches	Air	0	70	73.5	79.9	0.88	0.92
7	3.2 inches	Air	0.08	73.5	78.2	86	0.85	0.91
8	3.2 inches	Air	0.22	79.2	87.8	97.9	0.81	0.90
9	3.2 inches	Fresh Water	0	149.7	167.7	187.9	0.80	0.89
10	3.2 inches	Fresh Water	0.08	156.5	172	195.4	0.80	0.88
11	3.2 inches	Fresh Water	0.22	171.8	186	209.5	0.82	0.89
1	-	(Polyethylene)	-	198	-	213.3	0.93	-

1.5 New Method

We have got good results in benchmark test. But, field test have not so good. In the case of low stem quality, measured data are close to calculated line. These deviations are almost less than 20% [1]. In the case of high steam quality, measured data at 270ft and 1004ft depth(considering Slip ratio) are nearly 15% and 50% [1] respectively apart from calculated value. Then, optimization of the positioning of neutron detector was introduced into D-probe measurement system, just like a near/far ratio method. However, detector count rates will be change to the other rates by detector positioning. Therefore, we have adopted an investigation for surveying the best detector positions where Cd ratios are independent on the environmental condition. Cd ratio were calculated by original data, as shown in TableⅡ.

In this analyzing, three kinds of the distances between the neutron source and the detectors, were selected and the simulations have been done for the case of 2.2 inch cement layer, as shown in TableⅢ(Case20～31). The material of the cement layer was filled by air at first, and replaced by water, at the next. The steam density of 0.0 and 0.04 g/cc were adopted. These simulations were performed by McBend code.

At first, relationship of neutron count rates and distance from source to detectors give a graphic representation of Figure4 and 5. From these graphics, relationship of Cd ratio and distance from source to detectors give two formulas, as followed.

Cd Ratio = $(Y_{1Aair}-Y_{1Bair})/T_{1Aair} = (Y_{1AW}-Y_{1BW})/Y_{1AW}$…formula1

Cd Ratio = $(Y_{2Aair}-Y_{2Bair})/T_{2Aair} = (Y_{2AW}-Y_{2BW})/Y_{2AW}$…formula2

From these formulas, relationship of distance from source to detector A and B give a graphic representation of Figure6. These relationships of distance from source to detectors will provide the Cd ratio which is independent on the environmental condition. In other words, these relations are near/far ratio.

Next, Cd ratio were calculated when distance from source to detector B was 67cm, as shown in TableⅢ(Case32～35). Formula Y_1 give a distance of 76.48cm to distance from source to detector A, when distance from source to detector B was 67cm. And, Formula Y_2 give a distance of 76.55cm to distance from source to detector A, when distance from source to detector B was 67cm. From the results (TableⅣ), new Cd ratio was not so received from the environmental condition. This direction is same as 0.00 [g/cm^3] steam density and 0.04 [g/cm^3] steam density.

<u>TableⅡ. Cd Ratio Analysis</u>

Distance from source to Detector A = 22.45 mm
Distance from source to Detector B = 22.95 mm

Case No.	Cement Layer Thickness	Cement Layer Material	Steam Density [g/cm^3]	Calculation Result [McBend] A	Calculation Result [McBend] B	Cd Ratio (A-B)/A
16	2.2 inches	Air	0	106.3	95.5	0.102
12	2.2 inches	Fresh Water	0	201.5	174.3	0.135
				Case12 / Case16 =		1.329
17	2.2 inches	Air	0.04	112.4	100.2	0.109
13	2.2 inches	Fresh Water	0.04	209.6	179.1	0.146
				Case13 / Case17 =		1.341

TableⅢ. Detector Positioning Analysis for Cd Ratio [Calculation Case]

Case No.	Cement Layer		Steam Density	Disyance from Source [mm]	
	Thickness	Material	$[g/cm^3]$	A	B
20	2.2 inches	Air	0	92.45	72.95
21	2.2 inches	Air	0.04		
22	2.2 inches	Fresh Water	0		
23	2.2 inches	Fresh Water	0.04		
24	2.2 inches	Air	0	82.45	62.95
25	2.2 inches	Air	0.04		
26	2.2 inches	Fresh Water	0		
27	2.2 inches	Fresh Water	0.04		
28	2.2 inches	Air	0	92.45	72.95
29	2.2 inches	Air	0.04		
30	2.2 inches	Fresh Water	0		
31	2.2 inches	Fresh Water	0.04		
32	2.2 inches	Air	0	76.48	67
33	2.2 inches	Air	0.04		
34	2.2 inches	Fresh Water	0		
35	2.2 inches	Fresh Water	0.04		

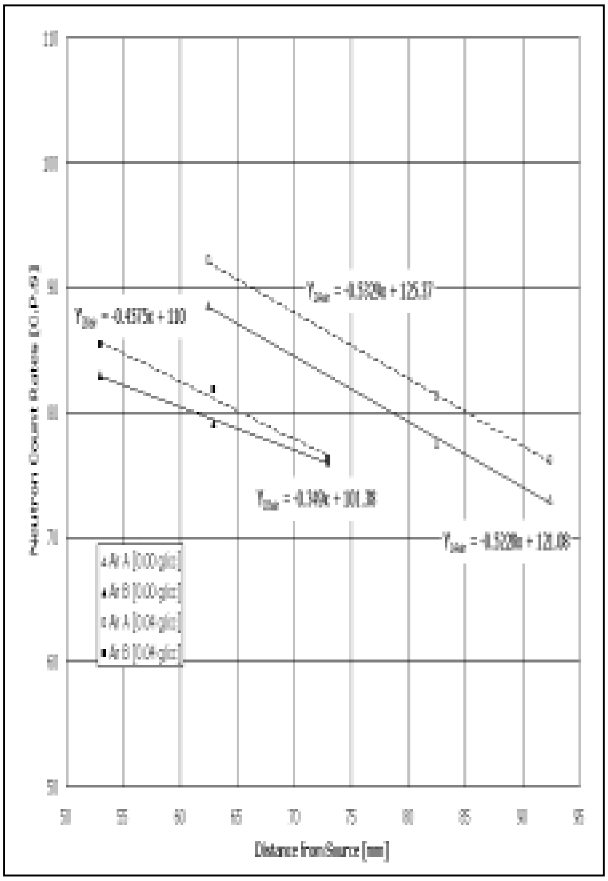

Figure 4. New Cd Ratio Analysis

[Steam Dnesity = 0.00 g/cm³]

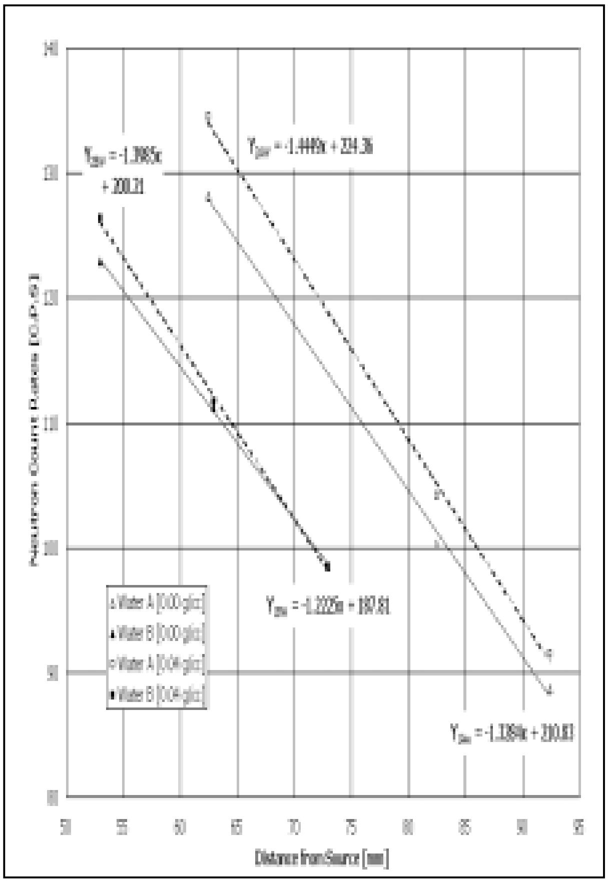

Figure 5. New Cd Ratio Analysis

[Steam Dnesity = 0.04 g/cm³]

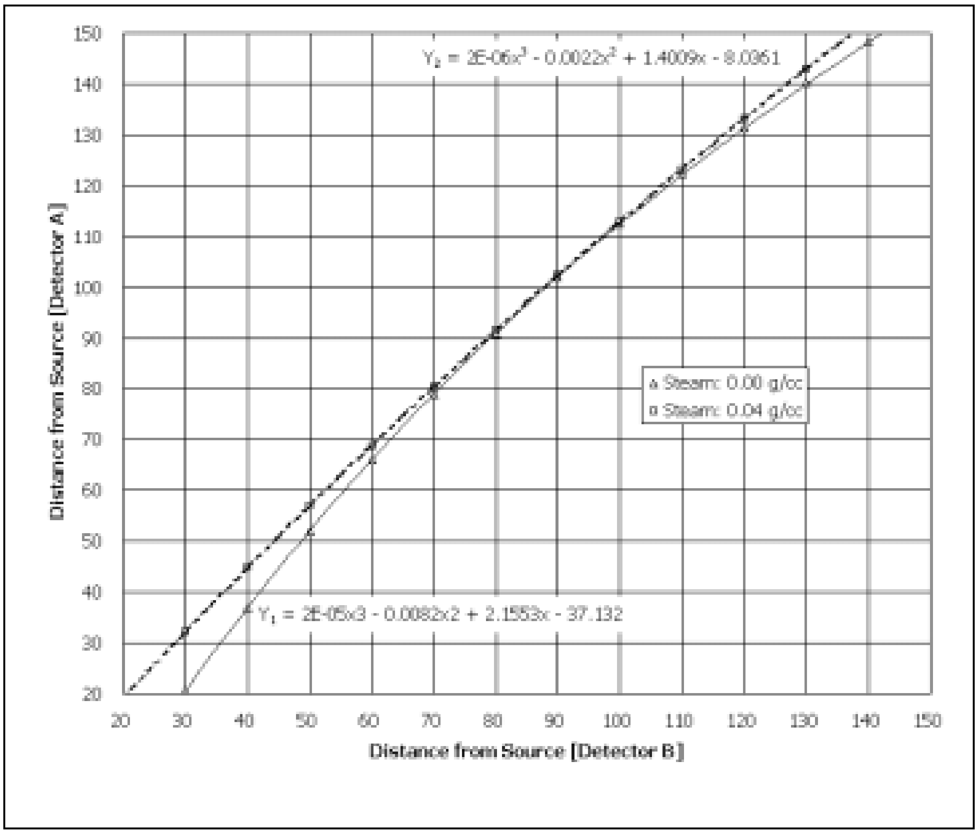

Figure 5. New Cd Ratio Analysis

[detector repositioning]

TableⅣ. New Cd Ratio

Distance from source to Detector A = 76.48 mm
Distance from source to Detector B = 67 mm

Case No.	Cement Layer		Steam Density	Calculation Result [McBend]		Cd Ratio
	Thickness	Material	[g/cm^3]	A	B	(A-B)/A
32	2.2 inches	Air	0	79.89	77.9	0.025
33	2.2 inches	Fresh Water	0	107.6	105.4	0.020
				Case32 / Case33 =		0.821

Distance from source to Detector A = 76.55 mm
Distance from source to Detector B = 67 mm

34	2.2 inches	Air	0.04	84.52	79.58	0.058
35	2.2 inches	Fresh Water	0.04	113.2	106.3	0.061
				Case34 / Case35 =		1.043

2 CONCLUSION

Comparing Table Ⅱ and Table Ⅳ, new Cd ratio is independent on the environmental condition apparently. We have devised a new method measuring a near/far ratio for measurement of steam density borehole inside. By the way, we were corrected the experimental data of benchmark test with near/far/ ratio formula Y_1 and Y_2, as shown in Table Ⅴ.

Therefore, Old Cd ratios were dependent on the cement layer material. But, the new Cd Ratio were dependent on the steam density.

If we have adopted a new near/far ratio method on the next measurement, we could get measured data what are independent on the environmental condition.

Table Ⅴ. Correction of Cd Ratio with new ner/far ratio formula

		Experiment			Corrected		
Cement Layer	Steam	A"	B"	Cd Ratio	*A"xA'/A*	*B"xB'/B*	*Cd Ratio'*
Air	0.00	106.3	96.8	0.089	79.89	78.96	*0.01164*
	0.04	108.4	98.6	0.090	81.51	78.31	*0.03929*
Fresh Water	0.00	225.8	196.7	0.129	120.58	118.95	*0.01352*
	0.04	227.8	198.9	0.127	123.03	118.05	*0.04046*

3 ACKNOWLEDGMENTS

The authors thank Dr.Kazuya Nishimura(Computer Software Development Co., Ltd.), Dr.Jeffry.S.Schweitzer(Connecticut University) and Dr.Ahmed Badruzzaman(Chevron Petroleum Technology Co.) in the development of the new near/far ratio analysis.

The authors thank Dr.Ian Carl(UKAEA), Dr.Pat Cowan(UKAEA) and Dr.Georg Right(UKAEA) in the simulation of McBend code.

4 REFERENCES

1. K.Nishimura, et al., “Measurement and Evaluation for the Steam Quality of the Steam Injection Well by Using the Steam Quality Evaluation Tool based on Neutron Method,” *The Third Well Logging Symposium of Japan*, Chiba Japan, September 24-25, Proceedings C pp.1-10 (1997).

2. K.Nishimura, et al., “Development of Downhole Steam Quality Measurement tool,” *Annual Meeting of the Japanese Association for Petroleum Technology*, Japan, June 11, 1993.

3. H.Yasuyuki, et al., “Development of Downhole Steam Quality Measurement tool,” *Annual Meeting of the Atomic Society of Japan*, Japan, Sepember 28-30, 1994.

4. K.Ono, “Successful Field Pilots in a Carbonate Heavy Oil Reservoir in the Ikiztepe Field, Turky,” *Journal of the Japanese Association for Petroleum Technology*, Vol.62, No.2 (1997).

5. Briesmeister,J.F., Ed., “MCNP-A General Monte Carlo N-Particle Transport Code, Version 4A,” LA-12625-M(1993).

6. Chucus,S.J.et al., “Preparing Monte Carlo Code McBend for the 21 Century,” *8th Int.Conf.on Radiation Shielding (ICRS-8)*, Arlington USA, April (1994).