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A Prediction Technique for Immiscible Processes Using Field Performance Data

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ABSTRACT

A prediction method based on the use of performance history of a waterflood proposed in 1978 by Ershaghi and Omoregie[1] is scrutinized here. Using a reservoir simulation approach, performance data for some hypothetical waterfloods are generated to test the application of the proposed technique to various flood patterns, reservoir properties, and field operating conditions. Recently published results on the behavior of relative permeability curves for immiscible processes are used to further substantiate the assumptions inherent in the proposed technique. The limitations of the technique are discussed and application to some actual case studies are presented.

INTRODUCTION

Conventional waterfloods and modified waterfloods using various additives still constitute the bulk of the fluid injection projects active in the United States and elsewhere.[2] During the history of a water injection project, reservoir engineers are expected to predict the future performance using the past response data. A review of literature shows that over the last forty years, there have been many techniques proposed for such prediction purposes.[3] These techniques range from empirical correlations to various analytical models. In addition to these techniques, the advent of reservoir simulation has resulted in the availability of a very powerful tool for performance prediction.

Many operators are still reluctant to use reservoir simulators because of insufficient reservoir data or insufficiently trained personnel to conduct simulation studies. The simple models often fail because of the assumptions inherent in such models as to the nature of the displacement mechanism or the inadequate representation of the real reservoir conditions.

Many years of field and laboratory research by the petroleum industry and the academia has resulted in a better understanding of the multitude of parameters influencing the efficiency of fluid injection projects. It has become a well-established fact that for immiscible displacements, reservoir heterogeneity, relative permeability characteristics, fluid viscosities and flood pattern are the most important factors.

No prediction method can successfully be used in a field project where the real reservoir is represented by laboratory derived data and inadequately defined reservoir heterogeneity. A successful prediction technique requires input from the real reservoir performance. A lumped parameter model that would embody all properties of the reservoir and the operating conditions can lead us to a realistic estimation of future performance.

In 1978, Ershaghi and Omoregie[1] presented a technique for extrapolation of water-cut vs. recovery curves in waterflood operations. The technique allows one to generate a field composite relative permeability ratio curve that includes reservoir properties as well as operational problems. The main assumptions were that first the plot of $\log(\frac{k_{rw}}{k_{ro}})$ vs. S_w is a straight line and second the leaky-piston displacement concept of Buckley and Leverett[4] is applicable.

Since the original publication, many operators have contacted the authors with questions and comments relative to the application of the technique to their specific cases ranging from natural bottom water drive to modified waterfloods. Two additional papers about the technique have appeared in the literature by others.[5-6]

This publication is aimed at clarifying certain ambiguities about the technique and to provide helpful guidelines for its application.

REVIEW OF THE TECHNIQUE

Assuming the $\log(\frac{k_{rw}}{k_{ro}})$ vs. S_w is a straight line,

References and illustrations at end of paper.

the concepts of fractional flow and the frontal advance theory proposed by Buckley and Leverett may be used to derive the following relationship between the recovery and the fractional water cut:

$$E_R = m \cdot X + n$$

where

E_R = recovery $\qquad X = \ln(\frac{1}{f_w} - 1) - \frac{1}{f_w}$

f_w = fractional water cut

$m = \frac{1}{b(1 - S_{wi})} \qquad n = \frac{1}{1 - S_{wi}}(S_{wi} + \frac{1}{b}\ln(A))$

$A = a \cdot \frac{\mu_w}{\mu_o} \qquad$ a and b from $\frac{k_{ro}}{k_{rw}} = a\,e^{bS_w}$

When some performance data on a developed waterflood are available, the data may be plotted on a cartesian paper (E_R vs. X) and from the slope and the intercept of the straight line values of a and b may be obtained. The plot itself can be used for extrapolation to higher water cuts. The values of a and b may be used to generate an effective field relative permeability plot given the estimates of S_{wi} and the viscosity ratio.

The generated plot, unlike the laboratory derived curves, is a composite curve which includes not only the displacement characteristics of the fluids, but also the reservoir geometry, heterogeneity and the operational conditions of the field.

Because of the nature of the function X, it was recommended in the original paper to restrict the use of the technique to fractional cuts above 50%.

ISSUES RAISED

The general questions raised with respect to the proposed technique and its application include the following:

1. Validity of the straight line assumption for the plot of the relative permeability ratio.

2. Lower limit of the 50% water cut.

3. Application to non-linear reservoirs and causes of deviations of the E_R vs. X plot from a straight line for some field applications.

In the following sections, we intend to respond to the above questions:

1 - Relative-Premeability Ratio Plot

The linearity of relative permeability plots vs. saturation on a semi-log graph can be observed on conventional laboratory derived plots. This issue has, in recent years, been treated extensively by Bardon and Longeron,[7] Asar,[8] and Amaefule and Handy.[9] These authors have reported on the effect of interfacial tension on the relative permeability ratio plots. In general, for high tension floods, such as a waterflood, the linearity is maintained to oil saturations close to the residual. For low tension floods, however, a curvature develops on the plots. The amount of curvature is inversely related to the interfacial tension.

2 - Water Cut > 50%

The lower limit of $f_w = 0.50$ has some practical implications. In a perfectly homogeneous system, one expects some clean oil production before the water breakthrough. Oil production before water breakthrough is controlled by the oil velocity exceeding water velocity. At breakthrough and afterwards, the water velocity is higher than the oil and from the definition of fractional flow $\left(f_w = \frac{1}{1 + \frac{k_{ro}}{k_{rw}} \cdot \frac{\mu_w}{\mu_o}}\right)$ f_w is above 0.5. This can be further substantiated from a typical fractional flow curve where the tangent to the curve at breakthrough results in a f_w larger than the f_w at the point of inflection (i.e., $f_w = 0.5$).

In real systems, because of substantial permeability variation, water channeling may occur before the oil bank is reached to the producing well and the water cut may increase before any substantial oil is produced.

The attainment of $f_w = 0.5$ signifies the overtaking of oil flow by water. It is this stage and beyond which is modeled by the proposed technique.

3 - Application to Non-Linear Reservoirs and Causes of Deviation from a Linear Trend

Studies conducted using reservoir simulation show that the original model developed for linear systems applies equally well for non-linear systems.

The effect of flood patterns, relative permeability curves, and permeability variations were studied for various hypothetical reservoirs using a reservoir simulation approach.

In the cases studied, we considered the displacement of a 20°API gravity oil by water. The fluid properties are shown in Table 1. Relative permeability data ranged from those shown in Fig. 1 (base case) to other variations incorporating changes in the curvature. A summary of cases run is shown in Table 2.

For cases 1, 2, 4, and 5 a single layer with a permeability of 350 md was modeled. The total injection rate was maintained at 600 BPD. Other properties of the model included an area of 120 x 120 sq. ft., a thickness of 28 ft., a porosity of 0.25 and an initial oil saturation of 0.8088.

In Case 1, the model considered four corner producing wells with a central injection well. Figure 2 shows the E_R vs. X plot for this case. The relative permeability ratio plot was made linear above $k_o/k_w = 0.06$. Thus in the transition region from $f_w = 0.5$ (X = .2) to $f_w = .832$ (X = - 2.805) the E_R plot shows a curvature. After a cut of 0.832 and to values as high as 0.98 the linearity of the plot is maintained.

Changing the pattern to a peripheral flood (Case 2), has very little influence on the projected recoveries under similar injection-production schedule, Fig. 3. In Case 3, the incorporation of a second layer with high permeability results in a straight line with a change of slope indicating higher water cuts at similar recoveries, Fig. 4. A comparison of the recovery plots for Cases 1 and 3 is shown on Fig. 5. The change of slope indicates that the composite relative permeability curve representing Case 3 is different from the data used in the model reflecting the higher velocities in the more permeable layer.

To further investigate the effect of the operational aspects two additional cases were studied for the model represented by Case 1. Using the same basic data, the injection was stopped after 7 years. The model performance was monitored and the E_R vs. X is shown in Fig. 6. A drop in cut results in the deviation from the straight line. Another case included a variable injection history. The effect of variable injection rate was investigated. The change in the level of injection results in a slight variation in the slope of E_R vs. X, Fig. 7. Resumption of the initial injection rate results in the formation of the initial slope on the E_R plot. The next test case included the effect of shutting-in one of the producers. Again a change in the slope results which is totally independent of the basic reservoir properties used, Fig. 8.

To generate data for low tension floods, the following equations were used for derivation of the base relative-permeability ratio plot.

$$k_{rw} = \left(\frac{S_w - S_{wc}}{1 - S_{wc} - S_{or}} \right)^{\alpha}$$

$$k_{ro} = \left(1 - \frac{S_w - S_{wc}}{1 - S_{wc} - S_{or}} \right)^{\beta}$$

Low tension floods are characterized with low exponents of α and β in the order of unity.[10] These equations are not applicable at the end points, thus we examined the graphs in the mid to upper ranges. Using $\alpha = \beta = 1.5$ results in a slight curvature in the shape of the relative permeability ratio plot, Fig. 9. Applying this plot to a model like Case 1 the E_R plot shown for Case 4 is obtained, Fig. 10. The deviation from a straight line is evident at recoveries above 32%.

If the waterflood is converted to a viscous flood, the E_R plot will show a change in the trend. This can be seen in Fig. 11 where a model similar to the Case 1 experiences a viscous waterflood of μ_w = 6 c.p. The plots of Fig. 2 and Fig. 11 are compared in Fig. 12. The two straight lines maintain the same slopes. Increase in water viscosity results in the shifting of the curve to higher recoveries.

From the case studies shown above, it is clear that the linearity of E_R vs. X is a function of the linearity of the relative permeability ratio plot and the field operational program. Anytime that the plot of the field data deviates from a straight line, a change in the properties of the injected fluid or in production-injection scheduling should be suspected.

In general, where the deviation from the E_R plot indicates a definite new trend because of changes in the field conditions, the new trend must be used for extrapolation purposes, Fig. 13.

IMPROVED GRAPHICAL TECHNIQUE

An improved graphical technique for the E_R plot was suggested by Robertson.[11] In this approach, a special coordinate system is created where one works directly with cut values and no conversion to X is required. A sample graph paper for use by the reader is shown in Fig. 14. Also a tabulation of X versus cut values from 0.501 to 0.999 is shown in Table 3.

CASE STUDIES

The application of the proposed method to various published waterfloods is reviewed below. The data are plotted as water cut in fraction versus recovery. Oil recoveries, depending on the source of the original data, are either in terms of fraction of original oil in place or in terms of cumulative production. For each case, if the data points deviate from a straight line, explanation from the source publication are included.

1 - Placer Lease, Tensleep

This study reported by Thompson[12] is about the behavior of a reservoir under water influx. Performance history plotted on the cut-cum plot shows a linear trend. The effect of shutting-in of the high water cut producers can be seen from the points above the straight line, Fig. 15.

2 - East Burbank[13]

This is the case of a stratified reservoir being waterflooded with numerous corrective actions throughout its life for minimizing water channeling. Figure 16 shows the cut vs. recovery plot. Two parallel straight lines are evident from the graph. The shifting of the original straight line to the right indicates the success of the stimulation job.

3 - Olympic Pool, Oklahoma[14] and Main and 99 East Pool, California[15]

Terrebonne[16] reported on the application of the proposed technique to the Olympic pool and the Main and East pool. Figures 17 and 18 show the cut-cum plots. For the Olympic pool, the data points form a linear trend. For the Main and 99 East pool the trend is deviated from the straight line by injectivity reduction into low permeability sands and the high injectivity of thief zones. Selective plugging operation resulted in the return of the performance plot to the basic trend.

SUMMARY AND CONCLUSIONS

The proposed method of cut-cum plot reviewed in this paper is applicable to waterfloods or modified waterflood at cut values above 50%. The exact starting point of the linear plot depends on the starting point of the linear trend of the relative-permeability ratio curve. The higher the water cut, the better the linearity of the cut-cum plot.

In real systems, the changes in volumetric sweep efficiency may cause deviation from an established linear trend for a given reservoir. Corrective actions such as selective plugging and shutting-in high water cut wells may result in the reestablishment of the original linear trend.

For prediction purposes, the late performance data may be extrapolated to high water cuts. Since for high tension floods relative permeability ratio curve approaches a linear trend at high water saturations, the proposed method should not be used during the early stages of a waterflood.

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TABLE 1

EQUALLY SPACED PRESSURE TABLE (DEPLETION DATA)
WATER - OIL - GAS PROPERTIES

	-- FORMATION VOL. FACTOR --			------- DENSITY -------			-- VISCOSITY --		SOLUTION
PRESSURE PSI	WATER STB/RVB	OIL STB/RVB	GAS MCF/RVB	WATER PSI/FT	OIL PSI/FT	GAS PSI/FT	OIL CP	GAS CP	GAS MCF/STB
800.0	0.98667	0.94340	0.28571	0.47004	0.42377	0.01757	17.40000	0.01280	0.10000
1000.0	0.98751	0.93023	0.36364	0.47044	0.41929	0.02237	16.40000	0.01300	0.12500
1200.0	0.98836	0.91743	0.44444	0.47084	0.41430	0.02734	15.70000	0.01380	0.13900
1400.0	0.98920	0.90380	0.52083	0.47125	0.41089	0.03204	15.20000	0.01430	0.17200
1600.0	0.99005	0.89286	0.60606	0.47165	0.40656	0.03728	14.80000	0.01473	0.20000
1800.0	0.99089	0.89445	0.70423	0.47205	0.40728	0.04332	14.60000	0.01515	0.20000
2000.0	0.99174	0.89606	0.76923	0.47245	0.40801	0.04731	14.40000	0.01555	0.20000
2200.0	0.99259	0.89767	0.83333	0.47286	0.40875	0.05160	14.32000	0.01595	0.20000
2400.0	0.99343	0.89928	0.92251	0.47326	0.40948	0.05674	14.24000	0.01635	0.20000
2600.0	0.99428	0.90090	1.00604	0.47366	0.41022	0.06188	14.19000	0.01675	0.20000
2800.0	0.99512	0.90253	1.09460	0.47407	0.41096	0.06671	14.17000	0.01715	0.20000
3000.0	0.99597	0.90416	1.17647	0.47447	0.41170	0.07236	14.15000	0.01755	0.20000
3200.0	0.99681	0.90580	1.24069	0.47487	0.41245	0.07631	14.14200	0.01797	0.20000
3400.0	0.99766	0.90744	1.31234	0.47527	0.41320	0.08072	14.13400	0.01839	0.20000
3600.0	0.99851	0.90909	1.36612	0.47568	0.41395	0.08493	14.13000	0.01860	0.20000
3800.0	0.99935	0.91075	1.39665	0.47608	0.41470	0.08591	14.13000	0.01860	0.20000
4000.0	1.00020	0.91241	1.42857	0.47648	0.41546	0.08787	14.13000	0.01860	0.20000
4200.0	1.00104	0.91408	1.47059	0.47689	0.41622	0.09045	14.13000	0.01860	0.20000
4400.0	1.00189	0.91575	1.51515	0.47729	0.41698	0.09329	14.13000	0.01860	0.20000
4600.0	1.00273	0.91743	1.54799	0.47769	0.41775	0.09522	14.13000	0.01860	0.20000
4800.0	1.00358	0.91912	1.56740	0.47809	0.41851	0.09641	14.13000	0.01860	0.20000
5000.0	1.00442	0.92081	1.58730	0.47850	0.41928	0.09763	14.13000	0.01860	0.20000
5200.0	1.00527	0.92251	1.65017	0.47890	0.42006	0.10150	14.13000	0.01860	0.20000

Connate water saturation	0.1910
Residual oil saturation to oil	0.31
Initial reservoir pressure	3563 psi
Water viscosity	0.45 cp

Table 2

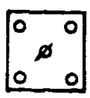
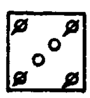
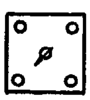
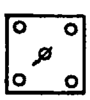
Case	Pattern	Rate Schedule	Remarks
1		Injection 600 B/D/W Production 150 B/D/W	Relative Permeability of Fig. 1
2		Injection 150 B/D/W Production 300 B/D/W	Relative Permeability of Fig. 1
3	 Layer 1 $\boxed{k = 350\ md}$ h = 23 ft Layer 2 $\boxed{k = 3500\ md}$ h = 5 ft	Injection 600 B/D/W Production 150 B/D/W	Relative Permeability of Fig. 1
4		Injection 600 B/D/W Production 150 B/D/W	$k_{rw} = \left(\frac{S_w - S_{wc}}{1 - S_{wc} - S_{or}}\right)^{1.5}$ $k_{ro} = \left(1 - \frac{S_w - S_{wc}}{1 - S_{wr} - S_{or}}\right)^{1.5}$

TABLE 3

Cut	X	Cut	X	Cut	X	Cut	X	Cut	X
.501	-2.0000	.555	-2.0227	.609	-2.0851	.663	-2.1850	.717	-2.3243
.502	-2.0000	.556	-2.0235	.610	-2.0867	.664	-2.1872	.718	-2.3273
.503	-2.0001	.557	-2.0243	.611	-2.0882	.665	-2.1894	.719	-2.3303
.504	-2.0001	.558	-2.0252	.612	-2.0897	.666	-2.1917	.720	-2.3334
.505	-2.0002	.559	-2.0260	.613	-2.0913	.667	-2.1939	.721	-2.3364
.506	-2.0003	.560	-2.0269	.614	-2.0928	.668	-2.1962	.722	-2.3394
.507	-2.0004	.561	-2.0278	.615	-2.0944	.669	-2.1984	.723	-2.3425
.508	-2.0005	.562	-2.0286	.616	-2.0960	.670	-2.2007	.724	-2.3456
.509	-2.0006	.563	-2.0295	.617	-2.0976	.671	-2.2030	.725	-2.3487
.510	-2.0008	.564	-2.0305	.618	-2.0992	.672	-2.2053	.726	-2.3518
.511	-2.0010	.565	-2.0314	.619	-2.1008	.673	-2.2077	.727	-2.3550
.512	-2.0011	.566	-2.0323	.620	-2.1025	.674	-2.2100	.728	-2.3581
.513	-2.0013	.567	-2.0333	.621	-2.1041	.675	-2.2124	.729	-2.3613
.514	-2.0015	.568	-2.0343	.622	-2.1058	.676	-2.2147	.730	-2.3645
.515	-2.0018	.569	-2.0352	.623	-2.1074	.677	-2.2171	.731	-2.3677
.516	-2.0020	.570	-2.0362	.624	-2.1091	.678	-2.2195	.732	-2.3709
.517	-2.0023	.571	-2.0372	.625	-2.1108	.679	-2.2219	.733	-2.3742
.518	-2.0025	.572	-2.0383	.626	-2.1125	.680	-2.2244	.734	-2.3774
.519	-2.0028	.573	-2.0393	.627	-2.1143	.681	-2.2268	.735	-2.3807
.520	-2.0031	.574	-2.0404	.628	-2.1160	.682	-2.2293	.736	-2.3840
.521	-2.0034	.575	-2.0414	.629	-2.1178	.683	-2.2317	.737	-2.3873
.522	-2.0038	.576	-2.0425	.630	-2.1195	.684	-2.2342	.738	-2.3906
.523	-2.0041	.577	-2.0436	.631	-2.1213	.685	-2.2367	.739	-2.3940
.524	-2.0045	.578	-2.0447	.632	-2.1231	.686	-2.2392	.740	-2.3973
.525	-2.0048	.579	-2.0458	.633	-2.1249	.687	-2.2417	.741	-2.4007
.526	-2.0052	.580	-2.0469	.634	-2.1267	.688	-2.2443	.742	-2.4041
.527	-2.0056	.581	-2.0481	.635	-2.1285	.689	-2.2468	.743	-2.4075
.528	-2.0061	.582	-2.0492	.636	-2.1304	.690	-2.2494	.744	-2.4110
.529	-2.0065	.583	-2.0504	.637	-2.1322	.691	-2.2520	.745	-2.4144
.530	-2.0069	.584	-2.0515	.638	-2.1341	.692	-2.2546	.746	-2.4179
.531	-2.0074	.585	-2.0527	.639	-2.1360	.693	-2.2572	.747	-2.4214
.532	-2.0079	.586	-2.0539	.640	-2.1379	.694	-2.2598	.748	-2.4249
.533	-2.0084	.587	-2.0552	.641	-2.1398	.695	-2.2625	.749	-2.4284
.534	-2.0089	.588	-2.0564	.642	-2.1417	.696	-2.2651	.750	-2.4319
.535	-2.0094	.589	-2.0576	.643	-2.1436	.697	-2.2678	.751	-2.4355
.536	-2.0099	.590	-2.0589	.644	-2.1456	.698	-2.2705	.752	-2.4391
.537	-2.0105	.591	-2.0601	.645	-2.1475	.699	-2.2732	.753	-2.4427
.538	-2.0110	.592	-2.0614	.646	-2.1495	.700	-2.2759	.754	-2.4463
.539	-2.0116	.593	-2.0627	.647	-2.1515	.701	-2.2786	.755	-2.4500
.540	-2.0122	.594	-2.0640	.648	-2.1535	.702	-2.2813	.756	-2.4536
.541	-2.0128	.595	-2.0653	.649	-2.1555	.703	-2.2841	.757	-2.4573
.542	-2.0134	.596	-2.0667	.650	-2.1575	.704	-2.2869	.758	-2.4610
.543	-2.0140	.597	-2.0680	.651	-2.1595	.705	-2.2897	.759	-2.4647
.544	-2.0147	.598	-2.0694	.652	-2.1616	.706	-2.2925	.760	-2.4685
.545	-2.0154	.599	-2.0707	.653	-2.1636	.707	-2.2953	.761	-2.4722
.546	-2.0160	.600	-2.0721	.654	-2.1657	.708	-2.2981	.762	-2.4760
.547	-2.0167	.601	-2.0735	.655	-2.1678	.709	-2.3010	.763	-2.4798
.548	-2.0174	.602	-2.0749	.656	-2.1699	.710	-2.3038	.764	-2.4836
.549	-2.0181	.603	-2.0764	.657	-2.1720	.711	-2.3067	.765	-2.4875
.550	-2.0189	.604	-2.0778	.658	-2.1742	.712	-2.3096	.766	-2.4913
.551	-2.0196	.605	-2.0792	.659	-2.1763	.713	-2.3125	.767	-2.4952
.552	-2.0203	.606	-2.0807	.660	-2.1784	.714	-2.3155	.768	-2.4991
.553	-2.0211	.607	-2.0822	.661	-2.1806	.715	-2.3164	.769	-2.5031
.554	-2.0219	.608	-2.0837	.662	-2.1828	.716	-2.3214	.770	-2.5070

TABLE 3 (cont.)

Cut	X	Cut	X	Cut	X	Cut	X	Cut	X
.771	-2.5110	.825	-2.7627	.879	-3.1207	.933	-3.7055	.987	-5.3430
.772	-2.5150	.826	-2.7682	.880	-3.1288	.934	-3.7205	.988	-5.4230
.773	-2.5190	.827	-2.7737	.881	-3.1370	.935	-3.7357	.989	-5.5100
.774	-2.5230	.828	-2.7793	.882	-3.1453	.936	-3.7511	.990	-5.6053
.775	-2.5271	.829	-2.7848	.883	-3.1537	.937	-3.7668	.991	-5.7107
.776	-2.5312	.830	-2.7905	.884	-3.1621	.938	-3.7827	.992	-5.8285
.777	-2.5353	.831	-2.7961	.885	-3.1706	.939	-3.7989	.993	-5.9620
.778	-2.5394	.832	-2.8018	.886	-3.1792	.940	-3.8154	.994	-6.1162
.779	-2.5435	.833	-2.8075	.887	-3.1879	.941	-3.8321	.995	-6.2985
.780	-2.5477	.834	-2.8133	.888	-3.1966	.942	-3.8491	.996	-6.5217
.781	-2.5519	.835	-2.8191	.889	-3.2054	.943	-3.8665	.997	-6.8095
.782	-2.5561	.836	-2.8249	.890	-3.2143	.944	-3.8841	.998	-7.2151
.783	-2.5604	.837	-2.8308	.891	-3.2233	.945	-3.9021	.999	-7.9088
.784	-2.5646	.838	-2.8367	.892	-3.2324	.946	-3.9204		
.785	-2.5689	.839	-2.8427	.893	-3.2416	.947	-3.9390		
.786	-2.5732	.840	-2.8487	.894	-3.2508	.948	-3.9580		
.787	-2.5776	.841	-2.8548	.895	-3.2602	.949	-3.9773		
.788	-2.5819	.842	-2.8608	.896	-3.2696	.950	-3.9971		
.789	-2.5863	.843	-2.8670	.897	-3.2792	.951	-4.0172		
.790	-2.5908	.844	-2.8731	.898	-3.2888	.952	-4.0378		
.791	-2.5952	.845	-2.8793	.899	-3.2985	.953	-4.0588		
.792	-2.5997	.846	-2.8856	.900	-3.3083	.954	-4.0803		
.793	-2.6041	.847	-2.8919	.901	-3.3183	.955	-4.1022		
.794	-2.6087	.848	-2.8982	.902	-3.3283	.956	-4.1246		
.795	-2.6132	.849	-2.9046	.903	-3.3384	.957	-4.1476		
.796	-2.6178	.850	-2.9111	.904	-3.3487	.958	-4.1710		
.797	-2.6224	.851	-2.9176	.905	-3.3590	.959	-4.1951		
.798	-2.6270	.852	-2.9241	.906	-3.3695	.960	-4.2197		
.799	-2.6316	.853	-2.9307	.907	-3.3801	.961	-4.2450		
.800	-2.6363	.854	-2.9373	.908	-3.3908	.962	-4.2710		
.801	-2.6410	.855	-2.9440	.909	-3.4016	.963	-4.2976		
.802	-2.6457	.856	-2.9507	.910	-3.4125	.964	-4.3249		
.803	-2.6505	.857	-2.9575	.911	-3.4236	.965	-4.3531		
.804	-2.6553	.858	-2.9643	.912	-3.4348	.966	-4.3820		
.805	-2.6601	.859	-2.9712	.913	-3.4461	.967	-4.4118		
.806	-2.6649	.860	-2.9781	.914	-3.4576	.968	-4.4426		
.807	-2.6698	.861	-2.9851	.915	-3.4692	.969	-4.4743		
.808	-2.6747	.862	-2.9921	.916	-3.4809	.970	-4.5071		
.809	-2.6796	.863	-2.9992	.917	-3.4928	.971	-4.5409		
.810	-2.6846	.864	-3.0063	.918	-3.5048	.972	-4.5760		
.811	-2.6896	.865	-3.0135	.919	-3.5170	.973	-4.6123		
.812	-2.6946	.866	-3.0208	.920	-3.5293	.974	-4.6500		
.813	-2.6996	.867	-3.0281	.921	-3.5418	.975	-4.6892		
.814	-2.7047	.868	-3.0355	.922	-3.5544	.976	-4.7300		
.815	-2.7098	.869	-3.0429	.923	-3.5673	.977	-4.7726		
.816	-2.7150	.870	-3.0504	.924	-3.5802	.978	-4.8170		
.817	-2.7201	.871	-3.0579	.925	-3.5934	.979	-4.8635		
.818	-2.7254	.872	-3.0656	.926	-3.6067	.980	-4.9123		
.819	-2.7306	.873	-3.0732	.927	-3.6203	.981	-4.9636		
.820	-2.7359	.874	-3.0810	.928	-3.6340	.982	-5.0176		
.821	-2.7412	.875	-3.0888	.929	-3.6479	.983	-5.0747		
.822	-2.7465	.876	-3.0966	.930	-3.6620	.984	-5.1354		
.823	-2.7519	.877	-3.1046	.931	-3.6763	.985	-5.1999		
.824	-2.7573	.878	-3.1126	.932	-3.6908	.986	-5.2689		

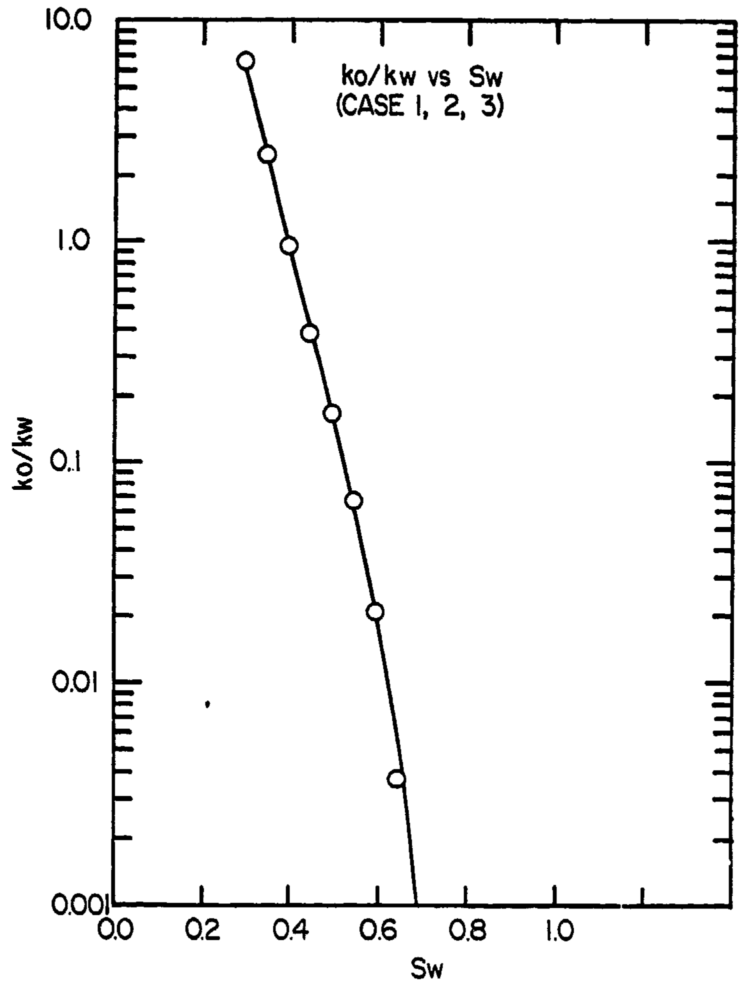


Fig. 1—Relative permeability ratio plot used for Cases 1,2

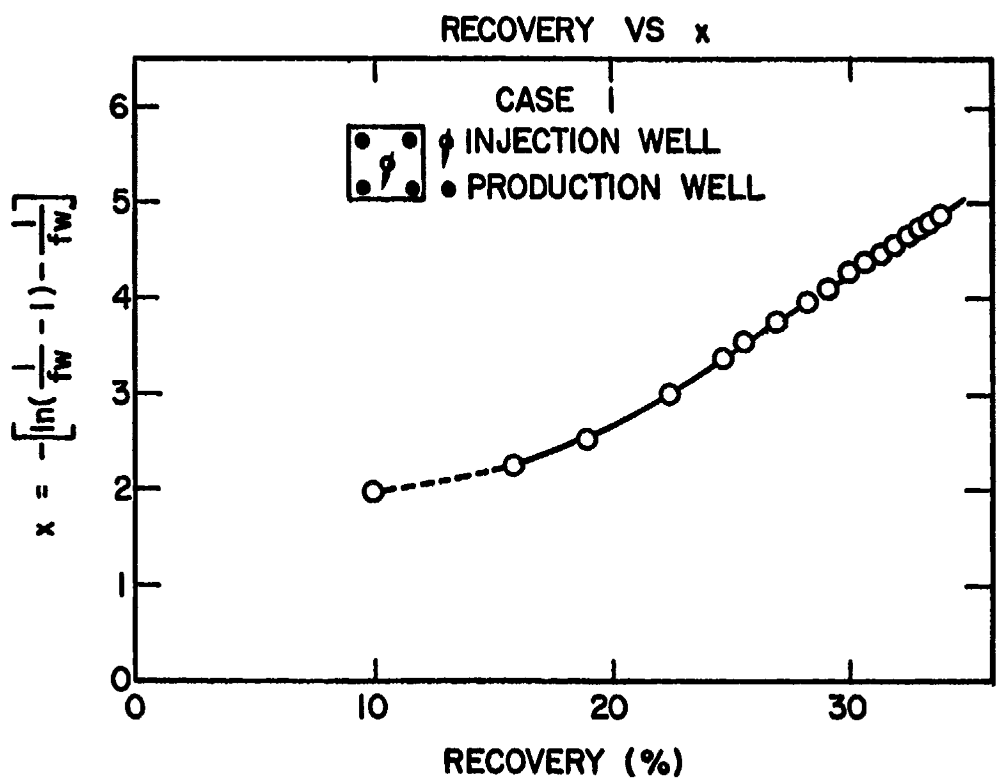


Fig. 2—Cut-Cum plot for Case 1

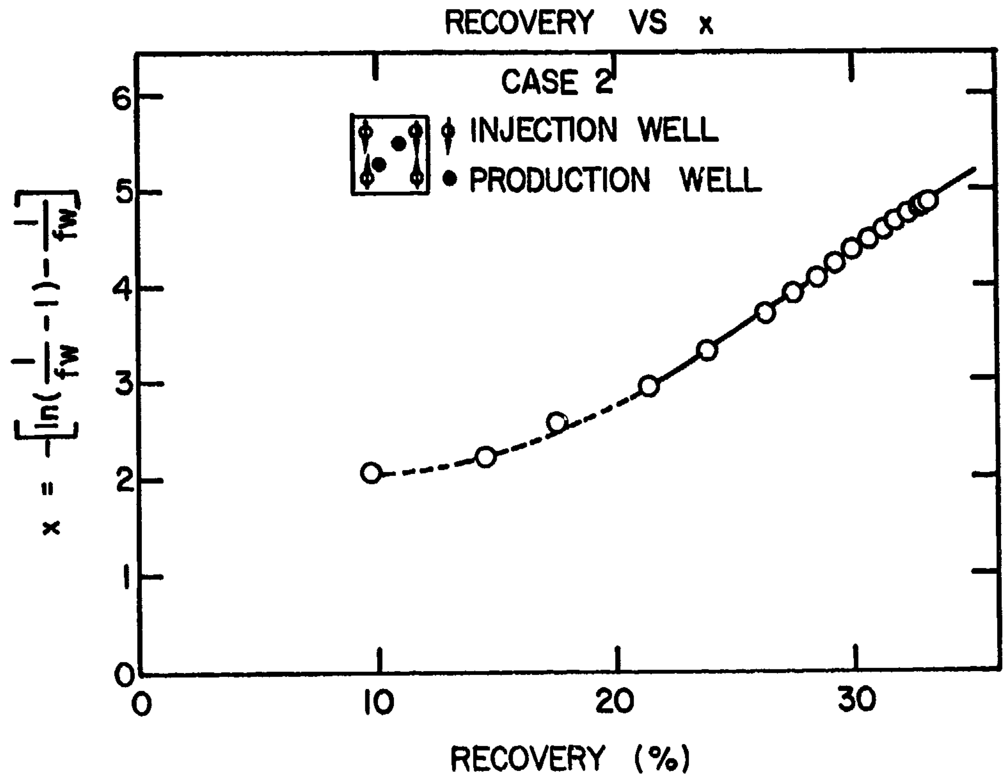


Fig. 3 – Cut-Cum plot for Case 2

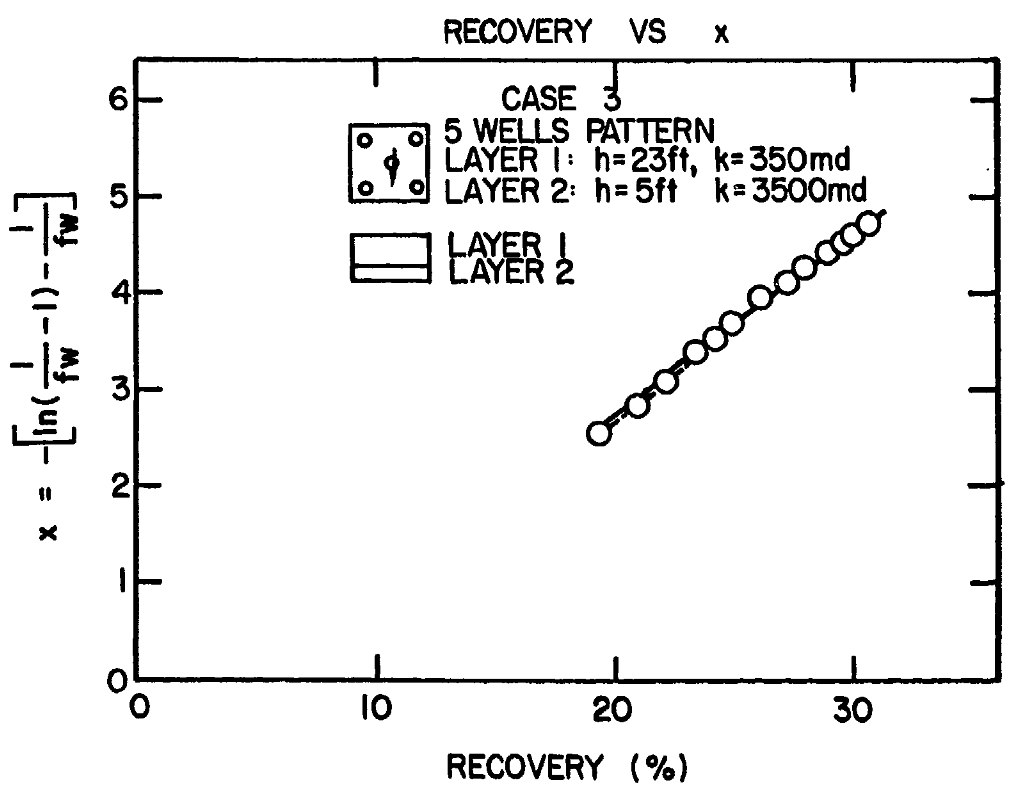


Fig. 4 – Cut-Cum plot for Case 3

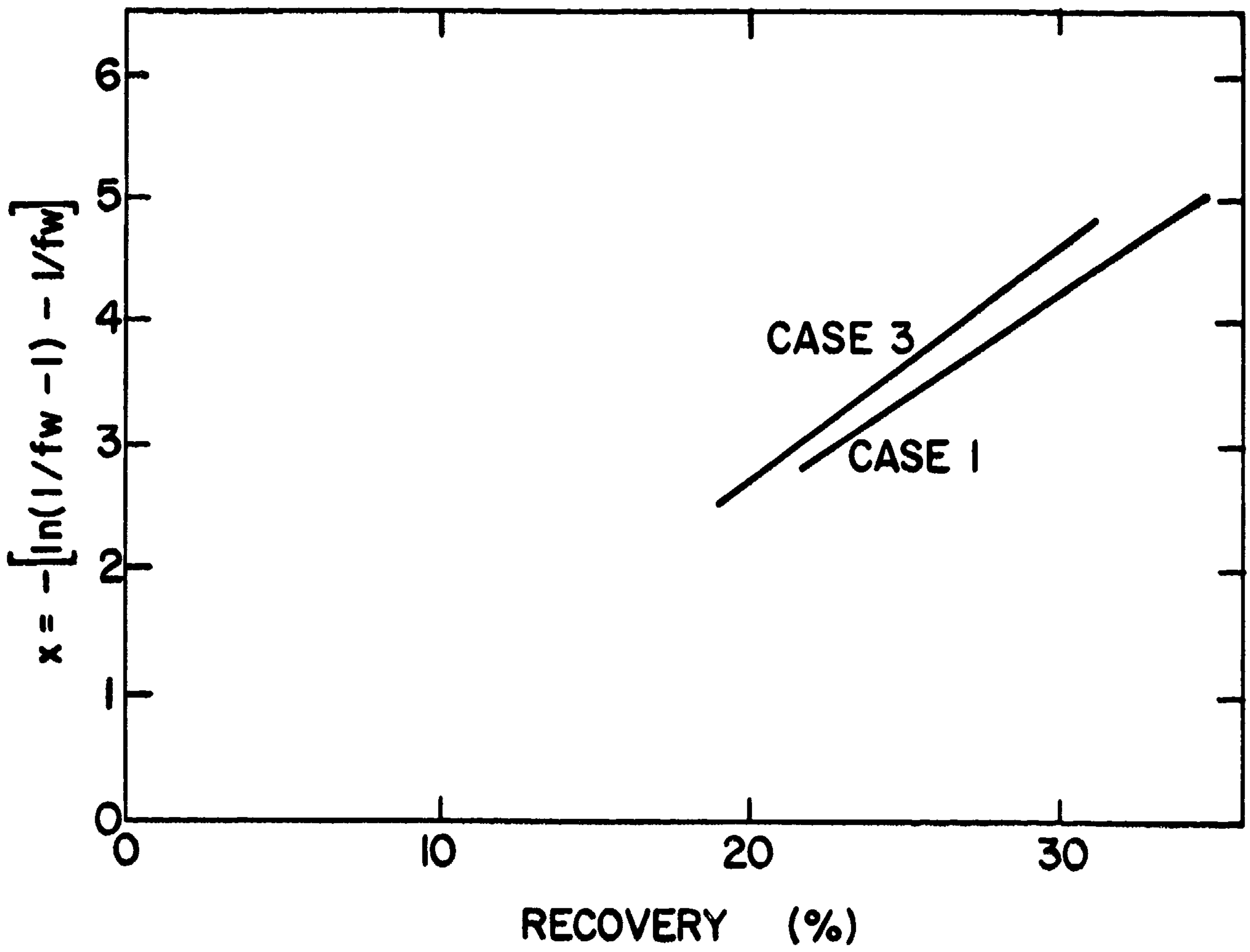


Fig. 5 -- Comparison of the performance for Cases 1 and 3

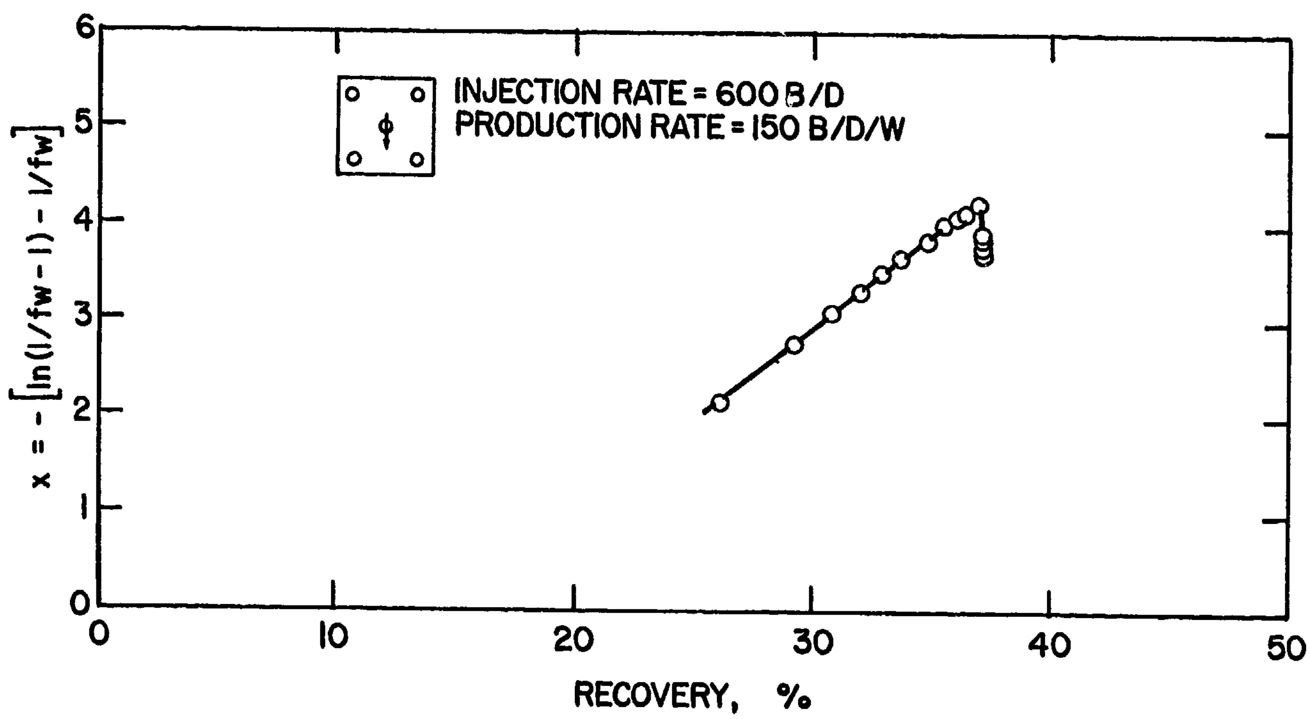


Fig. 6 – Cut-Cum plot for Case 1 if the injection stops after 7 years

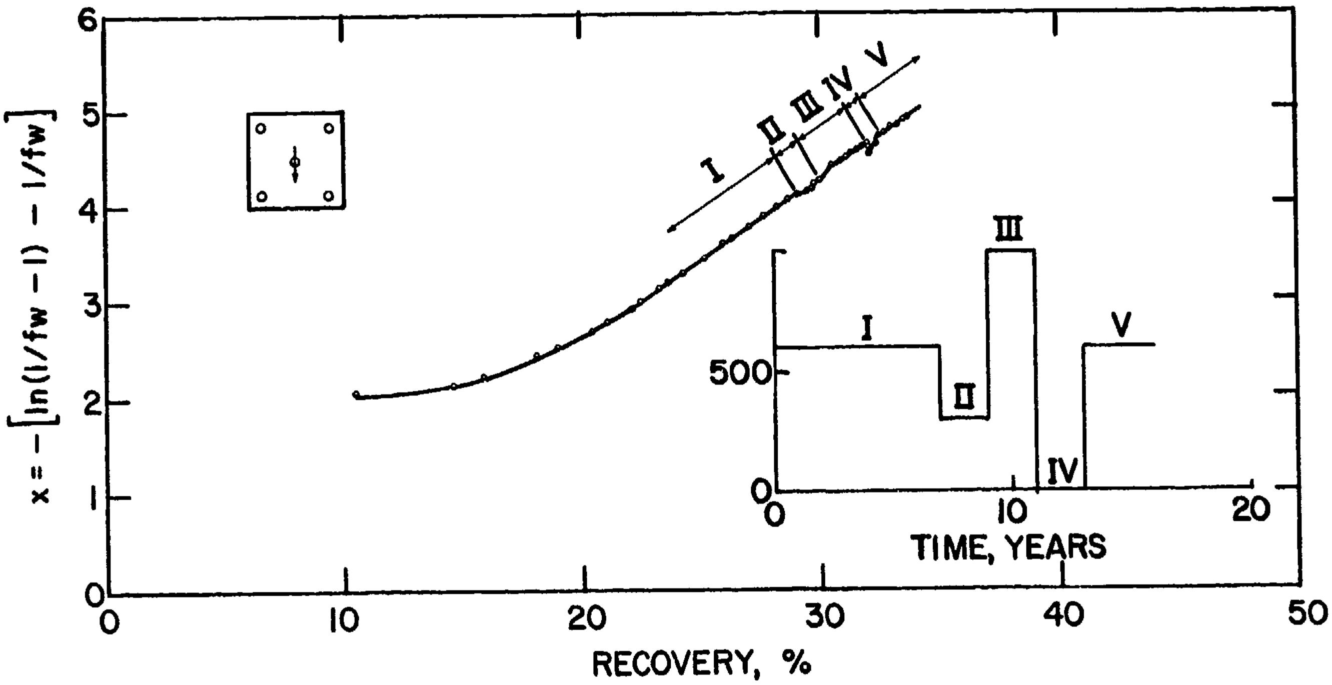


Fig. 7 – Effect of variable injection rate on the Cut-Cum plot of Case 1

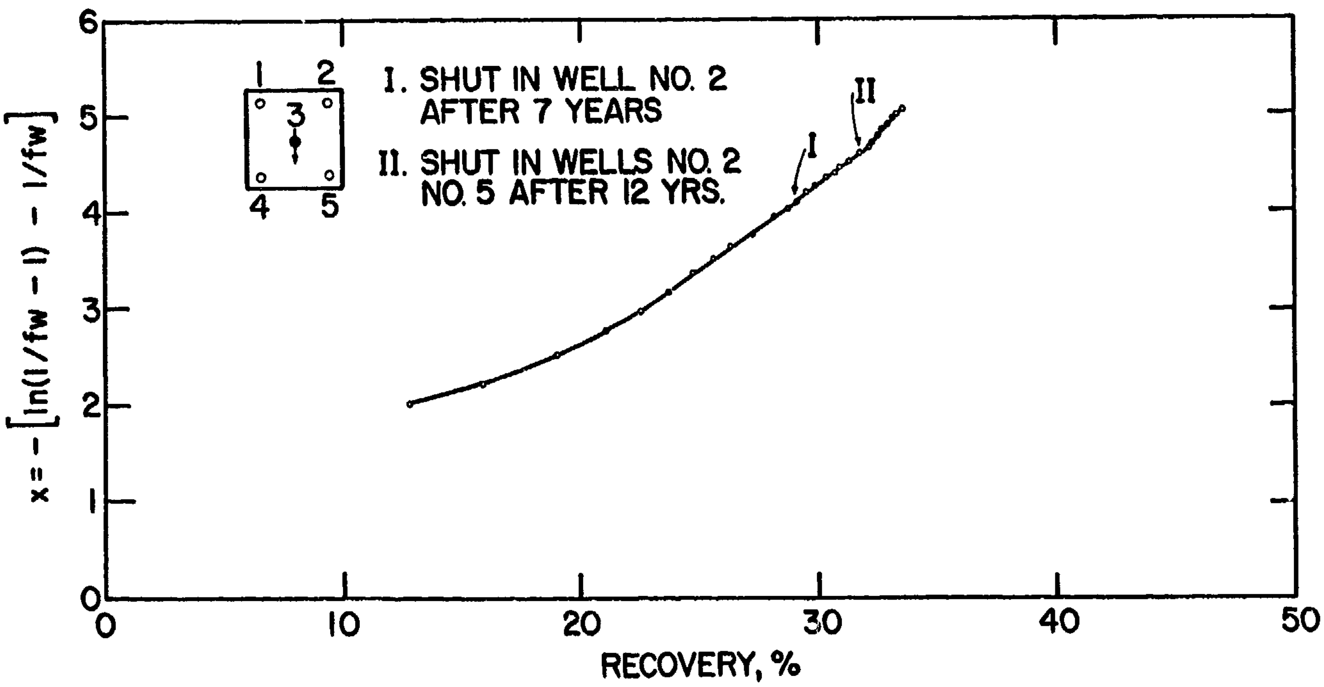


Fig. 8 – Cut-Cum plot for Case 1 if one or two producers are shut-in after some period

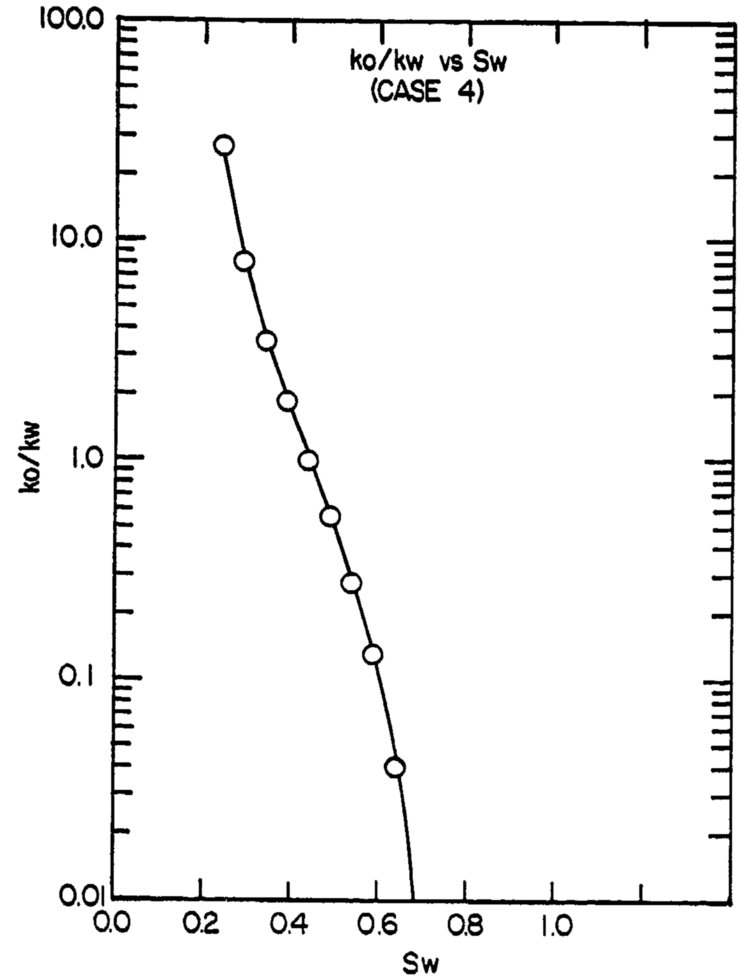


Fig. 9 – Relative permeability ratio plot generated for low tension floods

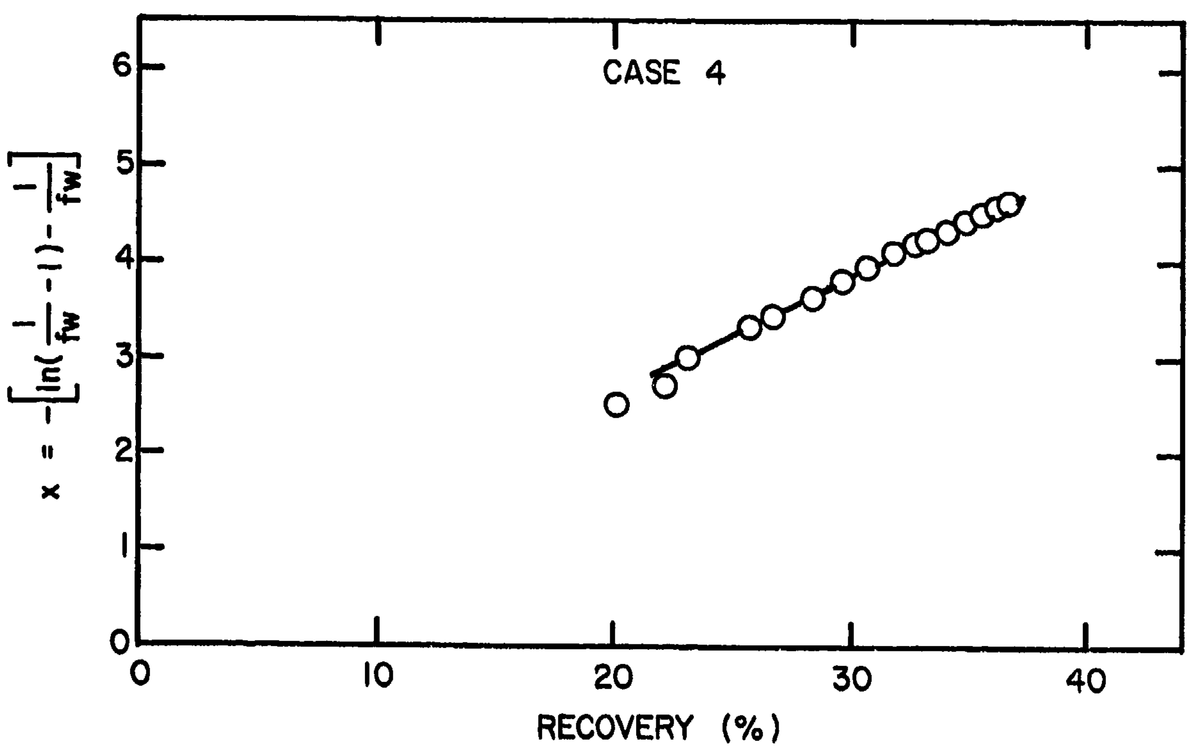


Fig. 10 – Performance of a low tension flood

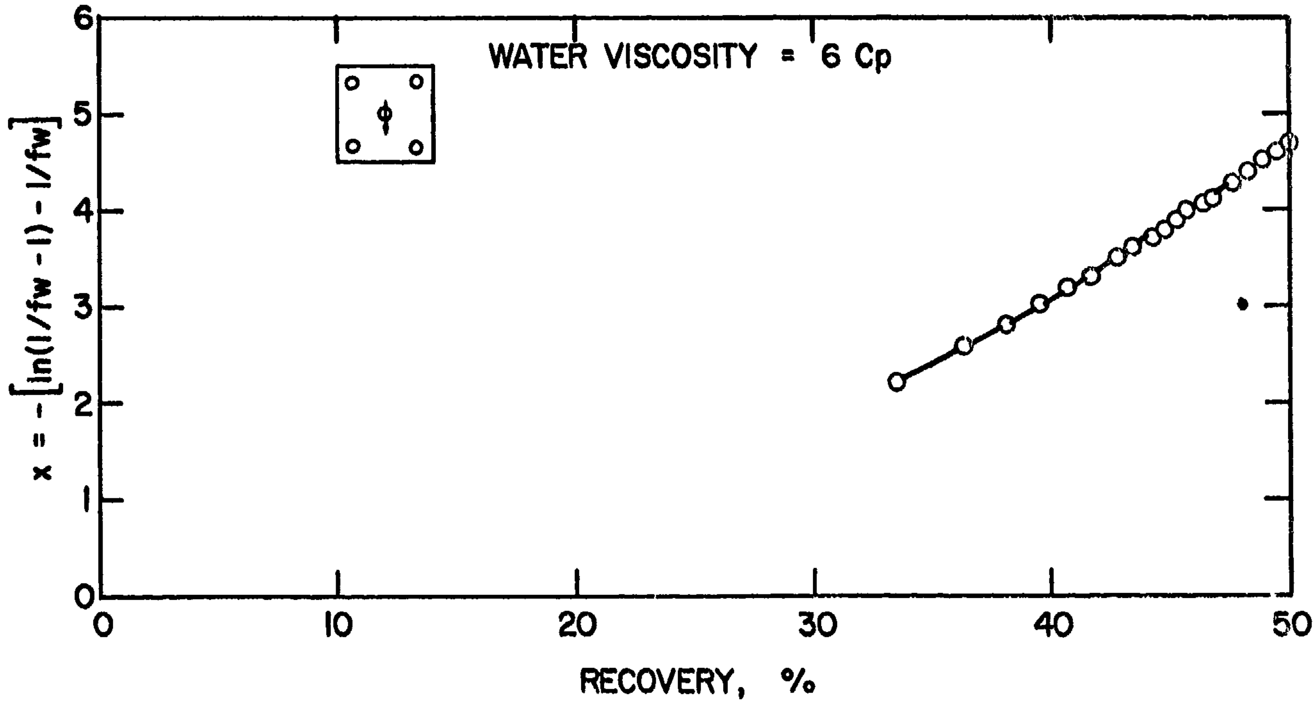


Fig. 11 – Cut-Cum plot for Case One under a viscous waterflood

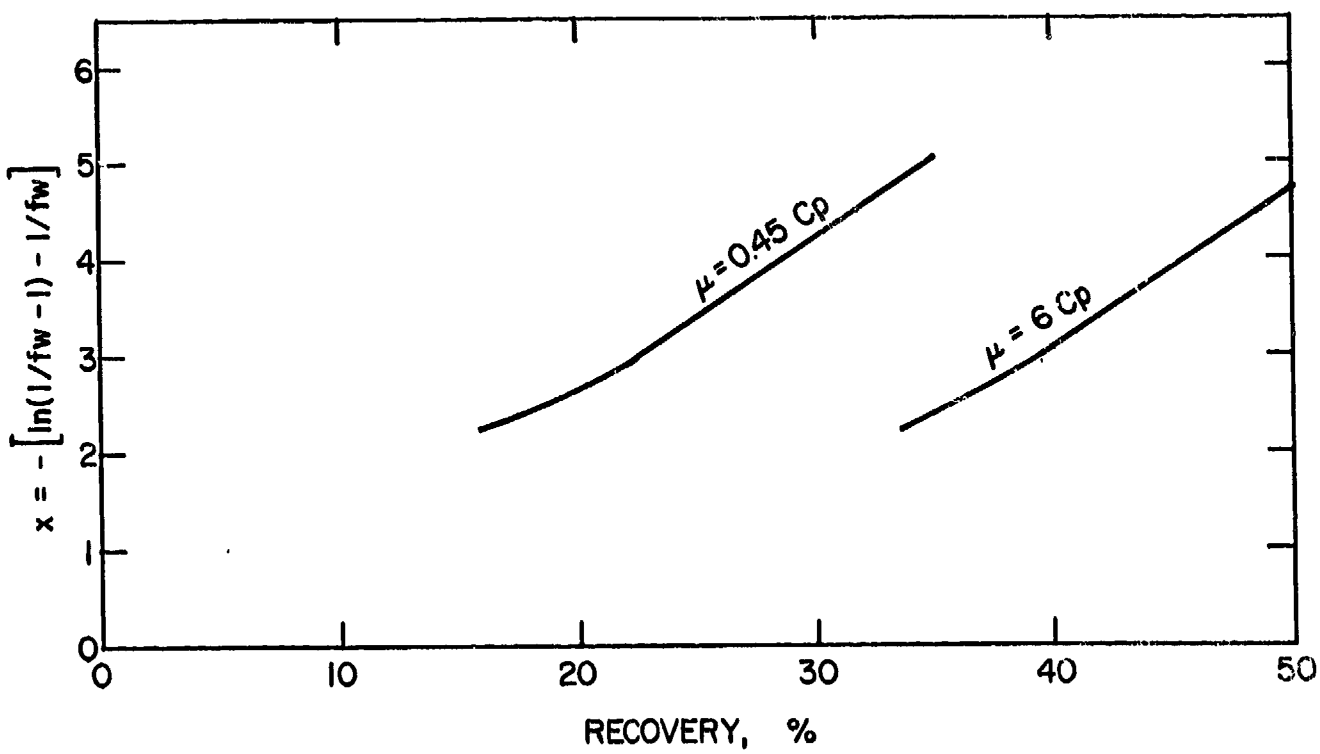


Fig. 12 – Comparison of Cut-Cum plots for low and high viscosity waters

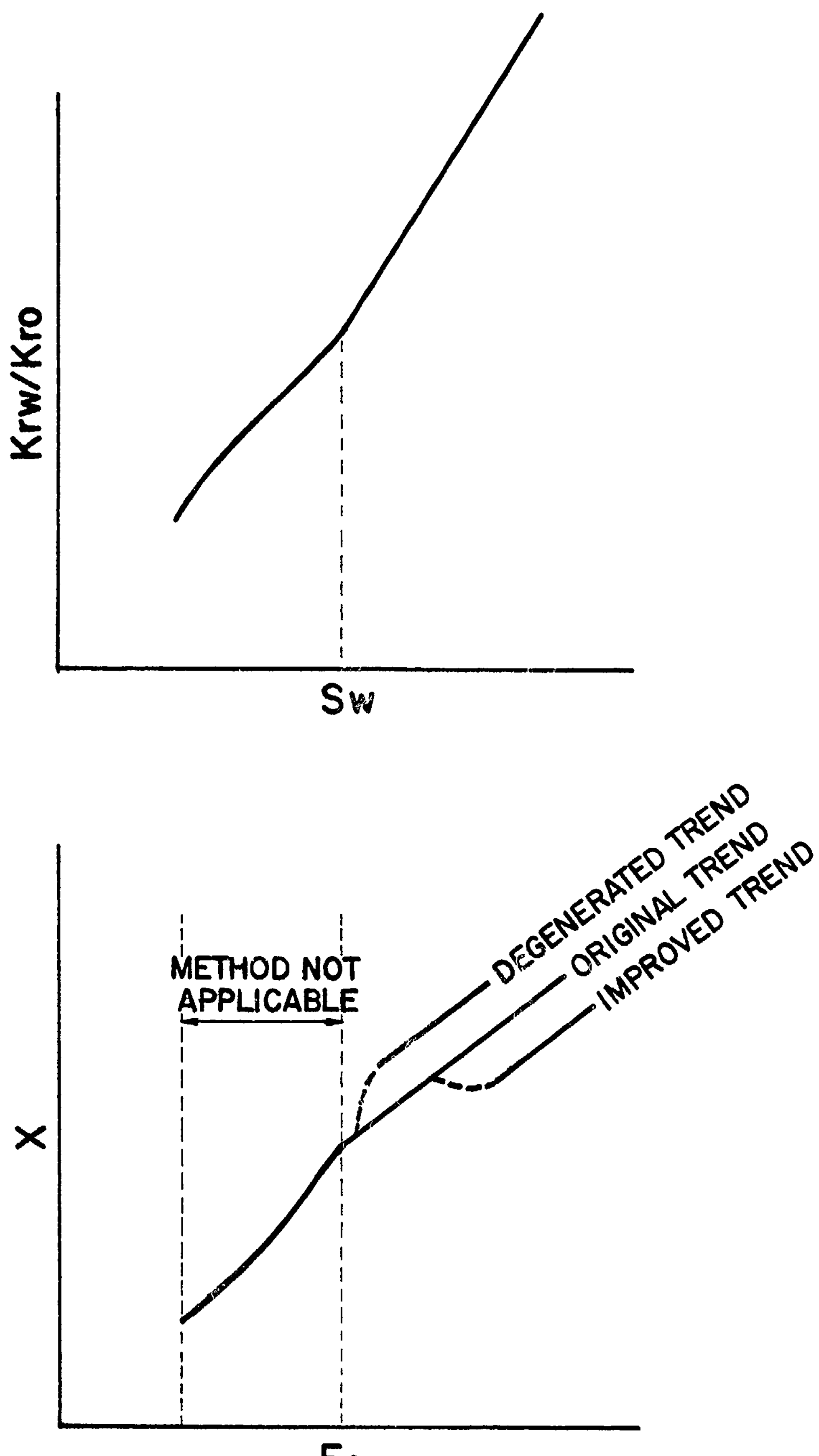


Fig. 13 – Changes in the trend of Cut-Cum plot

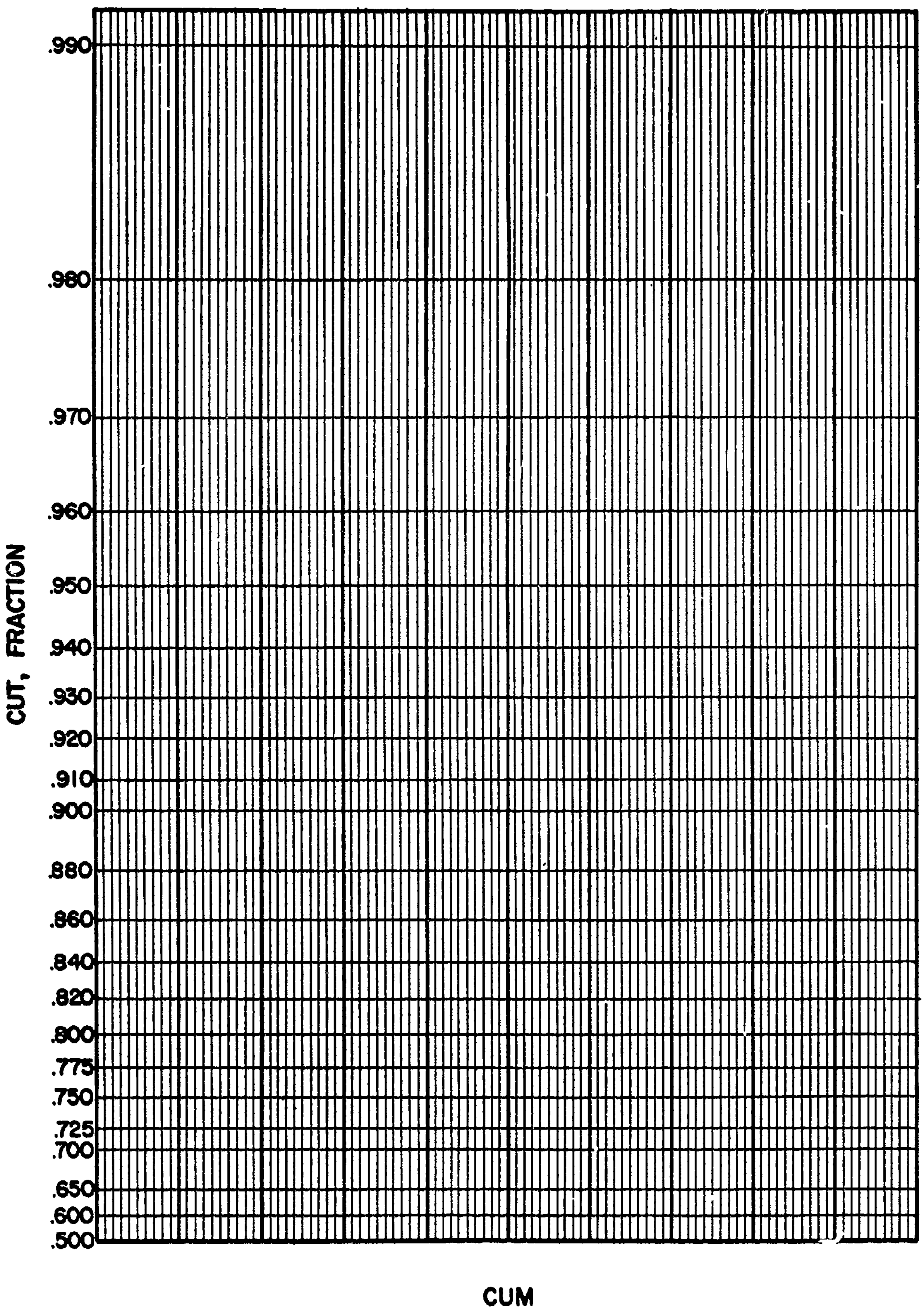


Fig. 14 – Improved graphical scale for plotting the Cut-Cum data

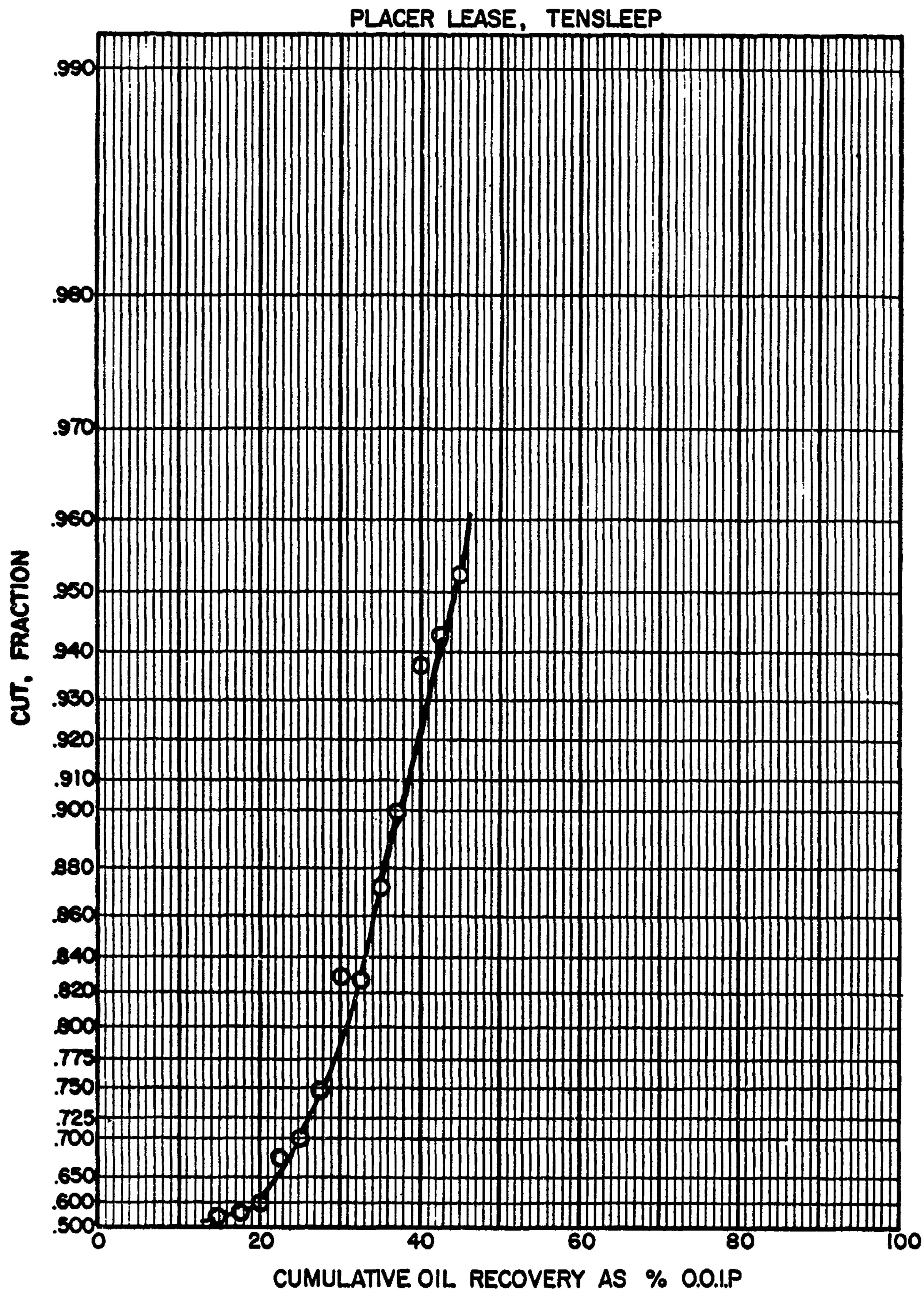


Fig. 15 – Performance of the Placer Lease, Tensleep on the Cut-Cum plot

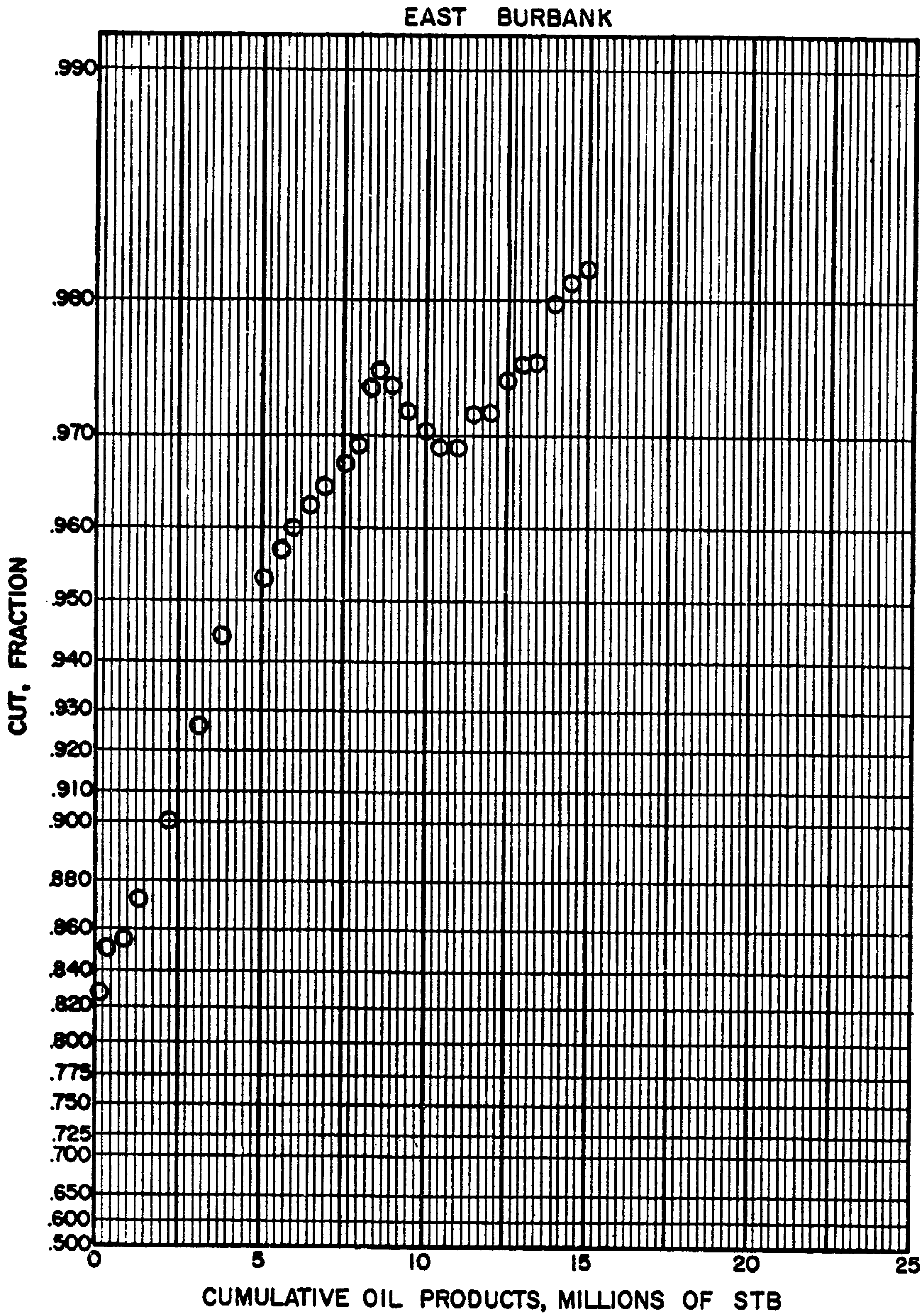


Fig. 16 – Performance of the East Burbank flood on the Cut-Cum plot

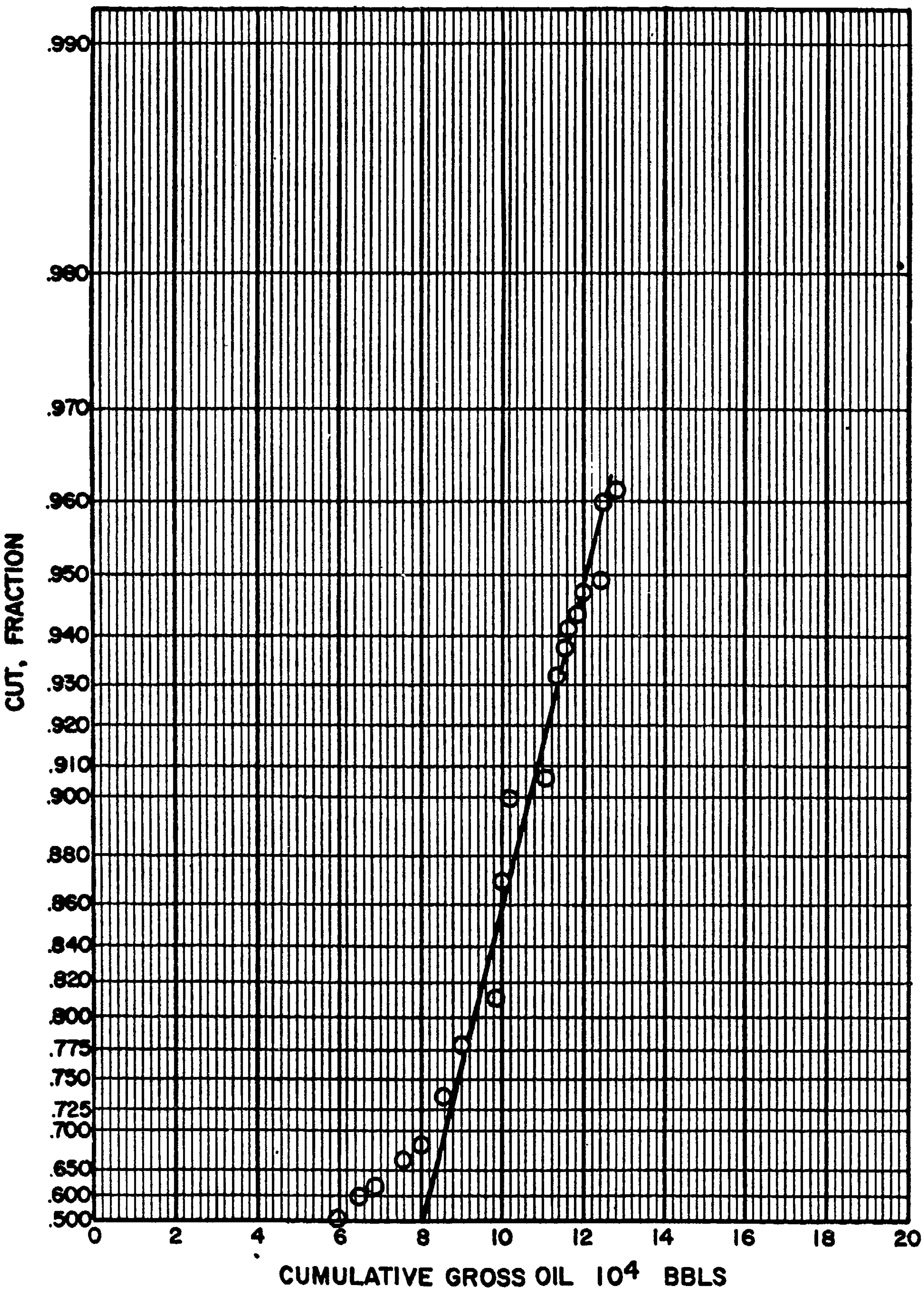


Fig. 17 – Performance of the Olympic Pool on the Cut-Cum plot

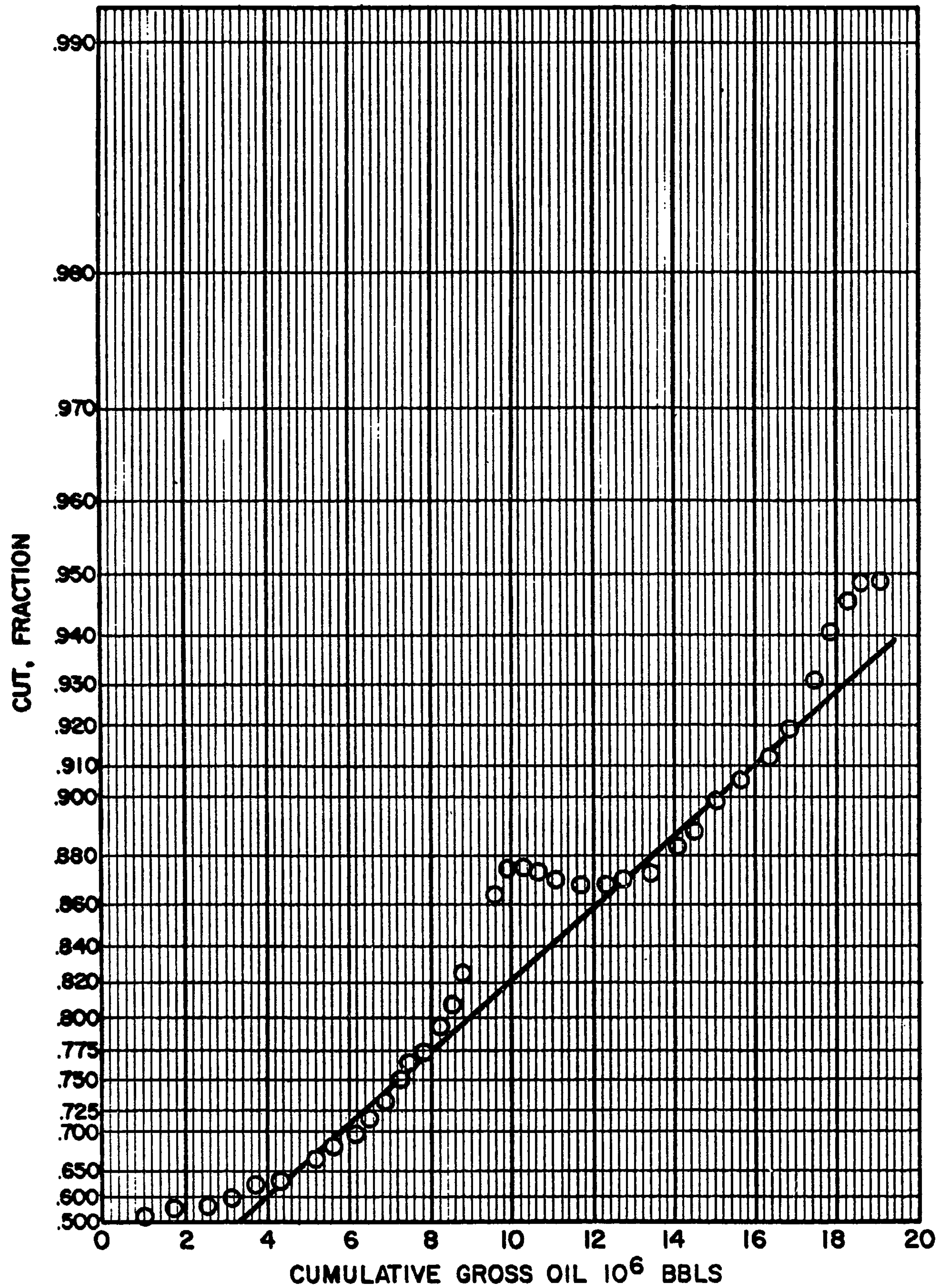


Fig. 18 – Performance of the Main and 99 East Pool on the Cut-Cum plot