Infill Drilling as Related to kh Contrast Between Injectors and Producers

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INTRODUCTION:

Infill drilling in conjunction with waterflooding is being used to accelerate production and improve recovery efficiency. Many authors have discussed the reasons for infill drilling and the factors which affect the success of an infill drilling project.[1,2,3,4,5,6]

Reservoirs are heterogeneous rather than homogeneous. van Everdingen[1] related this to spacing and infill drilling. He noted that the East Texas field has been developed on a five-acre spacing. Recovery in this field with close spacing will be about 87% whereas other fields usually average 30%. He studied a number of fields, both carbonates and sandstones, and noted that recovery efficiencies improved as acre-spacings decreased.

Barber et al[2] discussed the carbonates in West Texas. They reported that the reservoirs were found to be more discontinuous than originally thought as more wells were drilled. In the Fullerton Clearfork Unit infill wells were drilled and some producers were converted to injectors. The infill wells produced higher rates with lower water cuts than the offset wells. This was interpreted as additional pay being opened up with some of the pay not having been flooded. Thus, infill drilling increased reservoir continuity which they defined as the percentage of pay that is continuous from one well to the next.

Driscoll[3] reported on the factors affecting increased recovery after an infill drilling project. The one which ties in with our study is minimizing lateral discontinuities. Often a producing section will contain many pay zones which are vertically separated. In addition, these zones are often not continuous in a lateral direction. Closer spacing increases the percent of continuous pay.

The discontinuities are particularly evident in carbonates. This is also evidenced by the waterflood pattern used with a reservoir. Ghauri et al[4] note that in the West Texas Denver Unit initially a peripheral injection was used. However, because of the discontinuous zones, much of the reservoir was not being flooded. According to Stiles[5] there are three requirements for a pay zone to be successfully waterflooded:

a) Continuous and homogeneous between injector and producer
b) Injection supported
c) Effectively completed in offset producer.

Obviously, discontinuous zones will have some difficulty meeting the first and third requirements.

George and Stiles[6] reported on the Robertson, Fullerton and Means fields. They noted that these fields have many porosity stringers over several hundred feet of thickness. Some of these stringers are continuous over several thousand feet while others extend only a few feet. Rarely does one stringer cover the entire field. In addition, thicker formations such as these are more apt to have several permeable layers.

CONCEPT:

In Fig. 1 is a conceptual picture of a non-continuous pay. Some layers are continuous from one well to the next while other layers are not. "Dead end porosity" is a term used to indicate this situation - particularly in carbonates where it frequently occurs. Identifying areas with a large fraction of discontinuous zones would be advantageous to an infill drilling project. If one area is more discontinuous than another, it should respond more to infill drilling as untapped areas of the reservoir are opened up.

METHOD:

We have been running pressure buildups and falloffs on pumping wells by acoustically determining the liquid level, measuring the surface annulus pressure and calculating the bottom-hole pressure. The kh is calculated using the semilog slope with the total liquid rate, weighted average formation volume factor and total liquid mobility which is obtained from three-phase relative permeability curves. Thus, we have absolute permeability in our calculation of kh.

RESULTS:

We have conducted field studies in both carbonates and sandstones. Table 1 and Fig. 2 illustrate the good correlation between kh's on producers and offset injectors in sandstones. However, in carbonates we find sharp differences. We find that kh's on producers are higher than kh's on offset injectors. Note in Fig. 3 that this occurs consistently across the field. Table 2 contains the reservoir values for the wells in Fig. 3.

When this situation was first encountered, the lower kh's were attributed to poor quality injection water. Two of the limestone injectors were treated with solvents and acids and retested. The wells showed no change after the treatments.

Consider Fig. 4 which presents two adjacent wells - one a producer, one an injector. In the producer, all layers will contribute to the flow into the well and therefore to the kh calculated from a buildup. However, after a period of time in the injector, the discontinuous zones will become liquid filled and of uniform pressure, increasing the gradient in the remaining zones. When a pressure falloff is now run in the injection well, only the continuous zones will contribute to the pressure falloff giving the kh calculation. Thus, the injector will exhibit a decrease in kh compared to the producer, the difference being greater the larger the number of discontinous zones.

DISCUSSION:

We noted that the contrast in kh's between injectors and offsetting producers was more pronounced in some areas of the field than in others. In order to quantify this difference, we studied a ratio of kh of producer to kh of injector. Note Area 1 in Fig. 3. This area has an average ratio of 10:1. The rest of the field has an average ratio of 3:1.

The contrast in kh's was not restricted to just this field. It occurred consistently in other limestone fields that we studied. Table 3 contains reservoir values for the field in Fig. 5 which is another limestone. This example shows an even greater degree of contrast with areas having a ratio ranging from 3:1 up to 50:1. Fig. 6 is still another carbonate example, and Table 4 shows the corresponding reservoir values.

A high degree of discontinuity in a reservoir favors infill drilling. We believe marked contrast between kh values on producers and injectors suggests reservoir discontinuity. Those areas having a higher ratio would appear to be more favorable for infill drilling.

CONCLUSION:

a) Pressure buildups on producing wells and falloffs on injection wells can be used to identify areas of marked discontinuity in a carbonate field.

b) Those areas having the most contrast should respond better to infill drilling.

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1. van Everdingen, A. F. and Kriss, H. S.: "Why Can't We Get More Oil from the Ground?" Drill Bit (May 1981) 102-110.

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4. Ghauri, W. K., Osborne, A. F., and Magnuson, W. L.: "Changing Concepts in Carbonate Waterflooding - West Texas Denver Unit Project - An Illustrative Example," J. Pet. Tech. (June 1974) 595-606.

5. Stiles, L. H.: "Optimizing Waterflood Recovery in a Mature Waterflood - The Fullerton Clearfork Unit," paper SPE 6198 presented at the 1976 SPE Annual Fall Technical Conference and Exhibition, New Orleans, Oct. 3-6.

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Table 1

WELL #	KH	PD	X_f	Q_o	Q_w	Q_g
1	285	2192	0	37	8	45
2	64	2219	15	35	5	32
3	233	1638	34	57	10	66
4	170	1526	13	43	7	22
5	46	1721	14	21	2	36
6	20	1140	2	0	25	2
7	15	1859	12	8	4	2
8	40	5605	978		-338	
9	38	5548	1053		-389	
10	35	5394	565		-313	
11	28	4770	550		-300	
12	19	5363	788		-185	
13	12	5387	358		-95	
14	13	4735	542		-159	

Table 2

WELL #	KH	PD	X_f	Q_o	Q_w	Qg
1	138	2856	68	38	36	1.5
2	79	3635	88		-99	
3	46	4728	46	16	36	3
4	22	2896	285		-104	
5	65	2776	55		-216	
6	53	3088	472		-293	
7	178	2370	31	37	52	4.3
8	265	1705	16	30	18	NA
9	142	2370	15	10	157	2.1
10	42	3537	527		-215	
11	65	2712	27	21	20	19
12	30	3285	527		-108	
13	475	734	8	40	1	1.7
14	441	691	69	39	5	1.8
15	82	2548	68	12	63	2.1
16	452	1655	222	56	87	2.3
17	79	3443	496		-274	
18	55	3096	527		-282	
19	576	1115	35	96	14	3.6
20	23	2428	245		-155	
21	234	2185	55	65	42	4.8
22	42	3264	496		-147	
23	32	3595	376		-79	
24	321	1384	33	23	31	3
25	19	2618	527		-188	
26	390	923	6	16	30	1.8
27	23	3251	422		-92	
28	150	1426	29	12	15	20.4
29	201	850	12	15	3	4
30	397	684	0	8	13	3.4
31	14	1873	218		-167	
32	27	2975	215		-102	
33	5	3167	148		-19	
34	217	3820	589		-170	
35	260	1243	35	19	52	6.8
36	415	468	27	10	13	2.2
37	152	3685	745		-131	
38	187	605	0	6	1	2
39	36	3390	496		-111	
40	70	2043	67	12	6	1.2
41	71	3641	589		-123	
42	93	699	10	3	3	1

Area I:
Average Kh of Producer = 342
Average Kh of Injector = 31

Remaining Area:
Average Kh of Producer = 220
Average Kh of Injector = 67

Table 3

WELL #	KH	PD	X_f	Q_o	Q_w	Qg
1	131	892	50		-234	
2	3235	491	8	53	76	63
3	26	893	100		-100	
4	115	1310	120		-300	
5	47	1655	222		-100	
6	539	856	22	19	46	48
7	155	899	61		-500	
8	1401	803	0	48	19	12
9	86	973	58		-260	
10	129	1263	36		-260	
11	1092	945	9	56	83	15
12	483	2105	22	64	159	15
13	187	1421	262		-300	
14	140	1358	45		-300	
15	1669	779	3	35	148	5
16	31	1267	112		-90	
17	2180	353	7	19	24	24

Table 4

WELL #	KH	PD	X_f	Q_o	Q_w	Qg
1	130	2491	268		-324	
2	150	1552	31	9	31	2.3
3	135	2703	214		-285	
4	1038	298	29	8	12	2.4
5	97	2975	316		-129	
6	100	2573	483		-294	
7	976	241	9	6	4	4.6
8	158	2885	103		-188	
9	368	1042	29	10	64	3.9
10	315	2762	0		-74	
11	80	2818	366		-136	
12	1608	411	19	23	1	39
13	45	2350	241		-158	
14	200	1080	16	2	39	4.7
15	156	2747	426		-283	
16	104	2535	390		-291	
17	79	1781	60		-290	
18	569	1847	28	19	321	0.7
19	125	2319	230		-405	
20	173	1758	20	11	22	4.9
21	74	2080	251		-332	
22	143	2018	64		-430	
23	481	1437	65	30	140	2.9
24	78	2421	327		-260	
25	100	1957	306		-493	

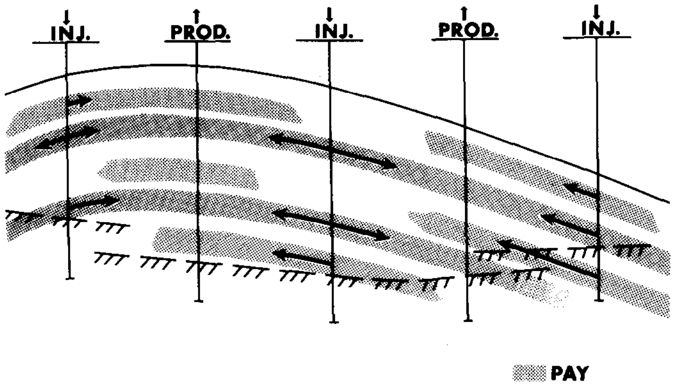

Figure 1 - Non continuous pay

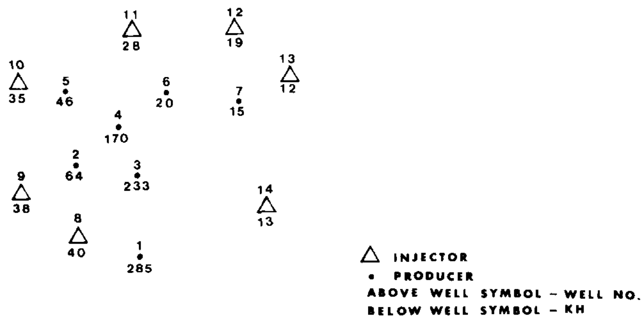

Figure 2

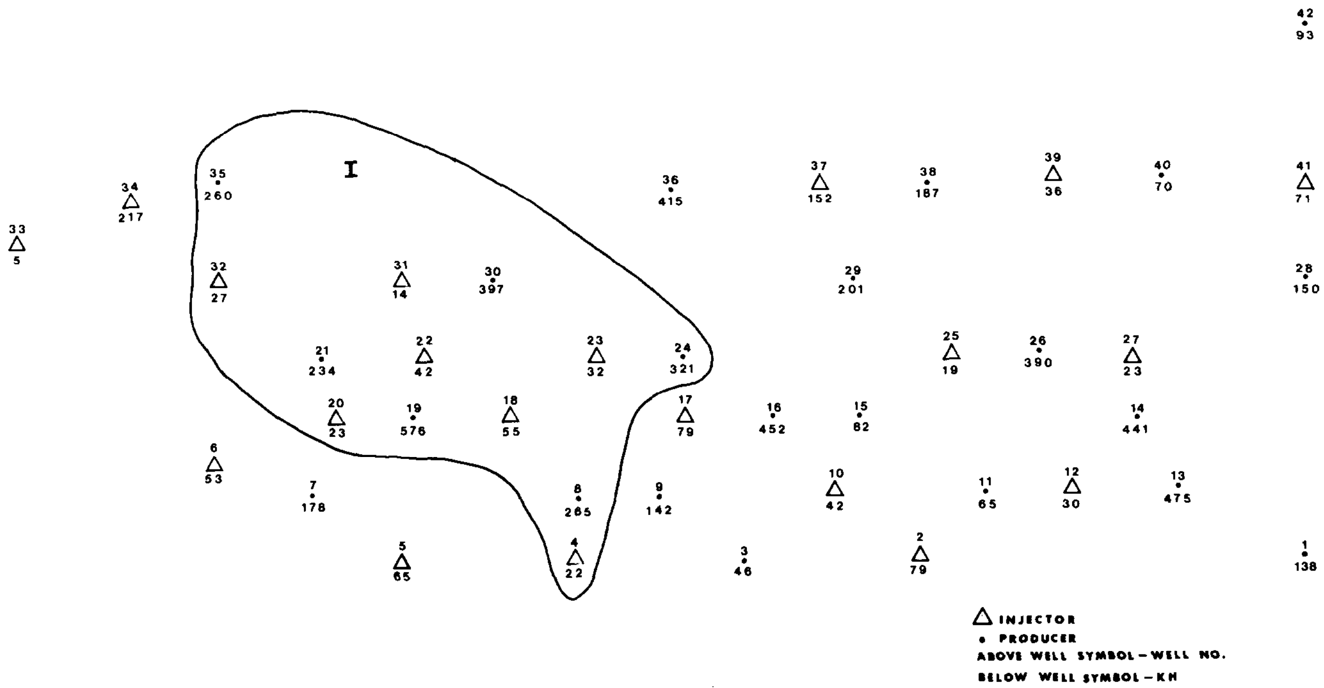

Figure 3

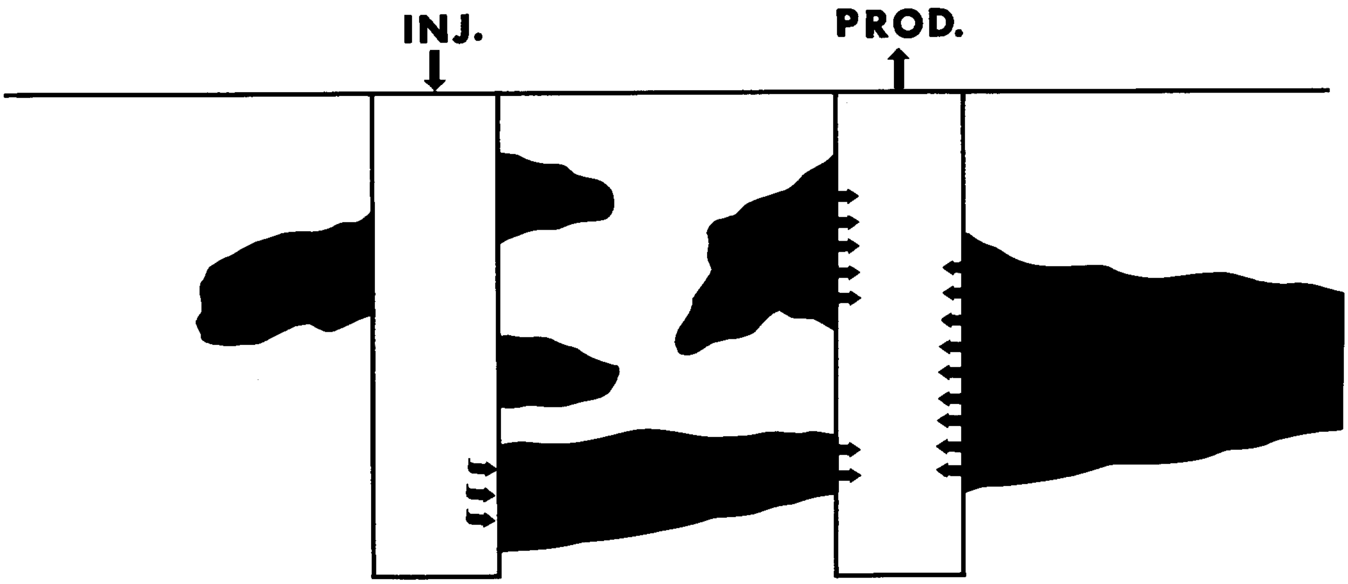

Figure 4

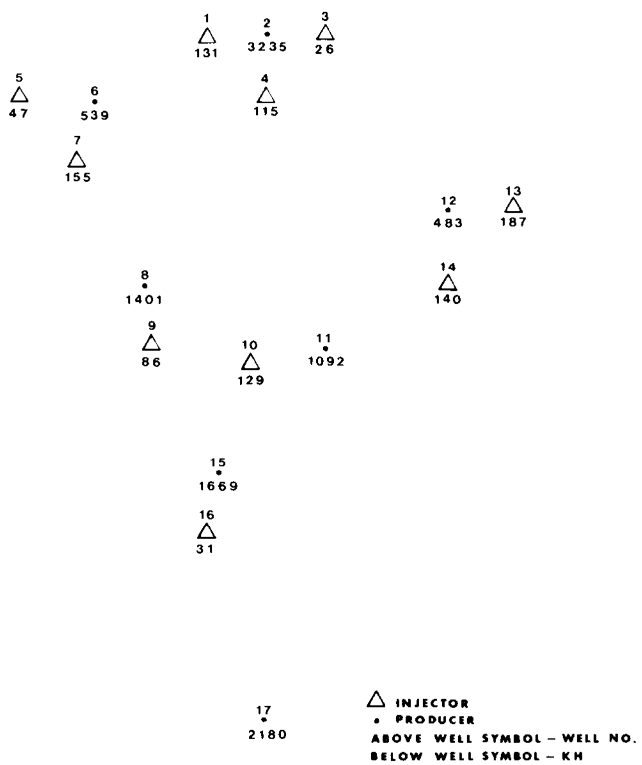

Figure 5

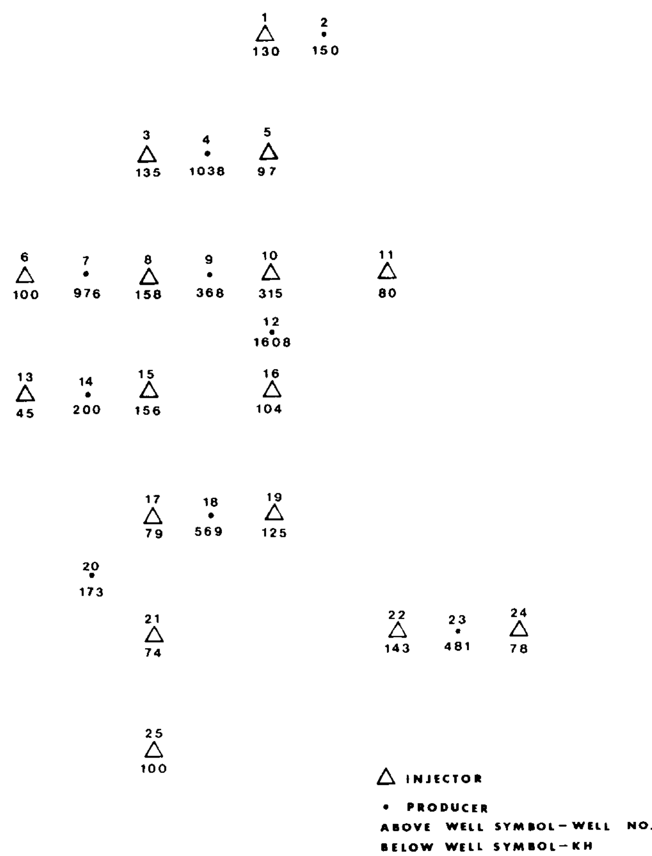

Figure 6