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APPLICATIONS OF EOR TECHNOLOGY IN FIELD PROJECTS

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ABSTRACT

Trends in the type and number of U.S. enhanced oil recovery (EOR) projects are analyzed for the period from 1981 to 1988. The analysis is based on current literature and news media and the Department of Energy (DOE) EOR Project Database which contains information on almost 1,300 projects. The National Institute for Petroleum and Energy Research (NIPER) maintains this data base and analyzes trends in the data under the provisions of Cooperative Agreement DE-FC22-83FE60149.

The most obvious trend is the steady decline in the number of project starts each year since 1981, which corresponds to the steady oil price decline during that period. The number of new projects started during the past year (mid-1987 to mid-1988) is leveling indicating project starts could have bottomed. Another trend is toward lower risk projects for which reservoir characteristics are the same as those of earlier successful projects. Despite the general lack of enthusiasm for EOR, several innovative techniques such as oil gravity mining, horizontal/slant well drilling, and microbial flooding are still being tried. Despite the temporary setback, long-term EOR prospects remain good, principally because EOR is one of the major sources of new oil reserves and could play a key role in the drive to maintain oil production through the year 2000.

INTRODUCTION

Under a cooperative agreement with the Department of Energy (DOE), the National Institute for Petroleum and Energy Research (NIPER) is collecting data on new and recently reported enhanced oil recovery (EOR) projects for the DOE EOR Project Database.[1] As part of this task, NIPER analyzes the technological and methodological trends in these projects. Analyzing trends includes determining which EOR processes are popular and why in addition to answering questions such as: are projects going deeper? are they becoming larger or smaller? are reservoir characteristics changing? and then determining why these things are or are not happening. These analyses show where new technologies are being applied and show, indirectly, where research has been successful and where additional research is needed.

Criteria of reservoir characteristics accepted as limits for successful EOR projects have been published elsewhere.[2] Projects with characteristics outside these limits are attempts to expand the accepted limits (field research) and are financially risky projects.

Initiation of EOR projects briefly increased in 1980 and 1981 but was followed by a gradual decline through 1985. The number of project starts declined rapidly from February 1986 to the present.

The most important factor affecting EOR projects is the price of crude oil, as shown in figure 1. The changes in average wellhead prices and refiners' costs since 1979 are shown in table 1. The rapid drop in the price of oil early in 1986 drastically changed the outlook for EOR. Oil production from EOR projects increased from 605,000 BPD in 1986 to 637,000 BPD in 1988[3-4], or about 5% in three years. However, the number of active projects decreased, and the number of new project starts remains down. The midyear 1988 estimate[5] for the wellhead price of crude oil was $14.65 (refiner's cost $17.70). In

spite of the drawbacks, the oil industry realizes the importance of EOR and remains financially committed to EOR's future. Research will continue to lower EOR costs[6] which suggests that as long as the expectation of price remains steady or is rising, more new projects will be started.

Late in 1985, the press was still reporting on the importance of EOR projects and how they were adding to the reserves of this Nation. Oil production from EOR projects was increasing[3-4] and the future looked bright. Some states passed, and other states were considering, tax incentives for EOR projects and by 1987 most producing states had done something to help the oil industry, but not much since most of these states also were facing tough economic times.[7-10]

As expected, most EOR projects are in the states that produce the most oil. California has the most EOR projects followed by Texas, Wyoming, Oklahoma, and Louisiana (table 2 and figure 2).

Trends in the characteristics of EOR projects started since 1980 as analyzed in this report are based mainly on the data in the EOR Project Database.[1] This database is kept up-to-date by NIPER and currently contains information on 1,296 EOR projects (735 started since 1980) as summarized in figure 3. Data on EOR projects started before January 1, 1988, collected by NIPER during the first half of 1988, are included in all tables in this report. In the major categories, thermal projects are the most popular followed by chemical. At the more specific process level, polymer flooding has the most projects followed closely by steamdrive.

It is important to note that popularity (number of projects) is not directly proportional to oil production. In 1987, thermal projects produced about 73% of the oil, as shown in figure 4, followed by gas injection projects. Polymer flooding, the most popular in terms of project starts, came

in sixth in terms of production which accounts for only 3.3% of the 1988 EOR production.[3]

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THERMAL PROJECTS

As shown in figure 4, thermal EOR processes are the most important of all EOR processes in terms of oil production, contributing about three-fourths of the total U.S. EOR production. The *Oil and Gas Journal*[3] reported a production of 480,000 BOPD (barrels of oil per day) from 201 active thermal projects in 1986 and estimate 465,000 BOPD from 152 active thermal projects in 1987. This decline in production was a direct result of lower oil prices. NIPER's version of the EOR Project Database contains information on 520 thermal EOR projects that had been started by January 1, 1988. More than 95% of the thermal oil production comes from steam projects, and more than 90% of the steam projects and production is in California.

According to the Division of Oil and Gas, State of California, oil production from thermal EOR projects declined about 5% following the drop in oil price early in 1986. However, by the end of 1986 production by thermal recovery methods had recovered to 172.7 million bbl compared to 170.9 million bbl in 1985. Most of this increase was the result of innovations and refinements in steam production technology such as cogeneration of steam and electricity. Some of the operators converted their steamfloods to hot water floods which accounted for about 40 million bbl of the 1986 thermal production. The effect of conversion to hot water may cause a future loss of production if steamflooding is not resumed.

Conventional Steam

Steamdrive is the most popular of the thermal processes, contributing more than two-thirds of the oil produced by those processes. The available information on steamdrive projects started in 1980 through 1987 is summarized in table 3. All of these projects are in sandstone formations, and over 90% of them are in California. Figure 5 shows that as oil price increased the number of steamdrive projects increased, with both peaking in 1981. Another small increase in project starts was seen in 1984 when the price of oil seemed to be stable. Data for 1987 clearly show the number of project starts was down again.

The areas in table 3 are reported to provide some concept of size. Reported sizes range from 1 to 5,070 acres. One problem is how a project's size is perceived by the operating company. One company might report a 5-acre project knowing it may be expanded later to 1,000 acres, whereas another company might consider that project as a 1,000-acre project with only 5 acres currently active. Over the period 1980 through 1982, the depth and range of API gravity of these projects increased as operators tried light oil steamflooding and more risky projects when the oil price was higher.

Cyclic Steam

No new cyclic steam (huff 'n' puff) projects were reported to have been started in 1987 and only one in 1986. Many of the steamdrive projects are preceded by the cyclic steam process but were not counted as projects under this process. Information is available on only seven project starts in the 80's, which is not enough information to establish separate statistical trends for this process so they are included with conventional steam projects. No perceivable changes in project trends were seen following this inclusion.

In Situ Combustion

No new in situ combustion project starts were reported in 1987, only one started in 1986, and two in 1985. As shown in table 4, there are not enough projects to show trends. Although it is not obvious from the table, 1980 was the peak year for this process which currently seems to be out of favor in this country.

Unconventional Steam and Heavy Oil

The unconventional steam process was defined originally as steamflooding at depths greater than 2,500 feet or to recover oils with API gravities lower than 10. The only valid trend shown in table 5 is in the number of project starts which correlates with oil price. As with other thermal projects, all starts were in sandstone reservoirs. There are not enough projects in this category to calculate any other trends. No new project starts were reported for 1986 or 1987.

CHEMICAL PROJECTS

Over the past few years, polymer projects have been the most popular (in terms of the number of new projects started) of all EOR processes, whereas surfactant and alkaline projects are still out of favor.[11] As a result of low oil prices, no new surfactant and alkaline projects were started in 1987. One polymer project did include a small amount of alkali and surfactant; however, the amount was so small that it required the label "polymer with chemical additive." The effect of oil prices on the total number of chemical project starts is shown in figure 6.

Estimated oil production[3] was 16,900 BOPD for 206 chemical EOR projects in 1986 and 22,500 BOPD for 124 projects in 1988. Although these numbers show a large increase on a percentage basis, the total oil production and production per project are small compared to that of thermal projects.

Surfactant Flooding

The surfactant (microemulsion, micellar-polymer, etc.) EOR process is complicated and expensive which is the reason the number of new projects started has declined so much since 1980. The number of projects (table 6) is too small to establish trends other than the decline of project starts with oil price. The peak year for surfactant EOR projects was 1980. During 1980 and 1981, more risky projects, (carbonates and deeper projects) were tried, which probably was the result of government incentives and rising oil prices. The few projects started in 1983, 1984, and 1985 were all in sandstone at moderate depths--low risk projects. No new project starts were reported for 1986 or 1987.

Polymer Flooding

Polymer flooding is the least expensive of the chemical EOR processes and by far the most popular in terms of new project starts. Most of these projects are in the midcontinent area. Polymer flooding continues to be the most popular chemical EOR process with five new projects started in 1987. The number of projects started by independent oil producers (table 7) peaked in 1981 when oil prices were high and then fell off until 1985 when it increased dramatically, as shown in figure 7. The cause of this rise is not fully known but probably was due to good economic results and better understanding from earlier projects. The recent drop in oil prices delayed or canceled 37 of the 38 polymer flood projects that were scheduled to start, according to the *Oil and Gas Journal's* 1986 report.[4] Although recovery for each polymer project is low, they are very popular because the cost per barrel of oil recovered is also low. The reason the peak for starts by all oil companies was delayed 2 years is not known; however, the possible exemption from the windfall profit tax may have been involved. Single-well profile

modification projects, although important, are not included in the database and are not evaluated in this report.

Project areas are given only as a guide for the reader; however, the overall increase in size with time is probably real. There appears to be a slight trend toward deeper projects; however, the deepest projects were started in 1982 and 1983. A few of the projects listed in table 7 may not have been started. Of the 38 polymer projects listed in the *Oil and Gas Journal* in 1986[4] only 1 was started and 6 were postponed. Few of these were included in the EOR Project Database. All EOR projects with start dates earlier than 6 weeks after a description is published are included. The research portion of the EOR project is likely to be completed and investors have made a commitment to implementing the technology. Most of the investment in time, equipment and materials has been made to get a project this close to starting injection.

Most projects continue to be in sandstone because of the degrading effect of calcium and other multivalent ions on the popular polyacrylamide polymer. No trends were observed for average API gravity or porosity. Average API is about 34 but covers a broad range as shown in table 7. Porosity also covers a broad range.

Other reservoir characteristics important in polymer flooding are type of polymer used, brine salinity, multivalent ion concentration, and reservoir temperatures. The type of polymer was reported only 25 times from 1980 through 1987. As expected, polyacrylamide was most popular with 88% of the projects, 8% were biopolymer, and 4% were cellulose-based. Only 20 values of salinity were found, all in 1980 and 1981 (table 8). Projects were started in waters ranging from fresh (238 ppm) to concentrated brine (195,000 ppm). Average salinity was 50,000 ppm. No values for calcium, magnesium, or any

combination of multivalent ions were reported for this time period. The data in table 8 indicate reservoir temperatures of polymer flood projects rose from 1983 to 1985. This is in agreement with depth trends in table 7. This trend is due to the development and application of more thermally stable polymers. Temperature was not reported for the projects started in 1987, but depths indicate that two were low-temperature with low risk and three were moderate temperature with moderate risk.

Alkaline Flooding

The alkaline flooding (caustic) process is complicated, moderately expensive, and applicable only to some acidic crudes which explains the small number of projects in table 9. Both of the new projects started in 1986 involve the use of another agent. One includes polymer and the other a small amount of co-surfactant. The only real trend is the decline in the number of project starts. The large number of projects started in 1980 resulted from the DOE Tertiary Oil Incentive program and rising oil prices. No new project starts were reported for 1982, 1984, 1985, or 1987.

GAS-INJECTION PROJECTS

The total number of active gas-injection projects[3] in 1988 had decreased 13.5%, from 104 in 1986 to 90 in 1988. Oil production from these projects increased from 108,000 BOPD in 1986 to 150,000 BOPD early in 1988[3]. The EOR Project Database (fig. 3) contains information on 283 gas projects reported as started by the end of 1987. Most (198) of these are miscible gas projects. The effect of oil price on project starts is shown in figure 8. The increase in project starts in 1980 and 1981 and the decrease in 1982 corresponds with oil price. The reason for the small peak in 1983 is unknown. The increase in 1985 and 1986 possibly indicates that oil companies expected oil price to level off or increase. The commitment to the technology in the form of

research, pipelines, and equipment had occurred long before the 1986 oil price collapse. NIPER has modified the EOR Project Database so these projects are identified by gas type in addition to whether they are miscible or immiscible. Carbon dioxide miscible projects and hydrocarbon gas projects are discussed under the miscible heading followed by immiscible carbon dioxide and nitrogen projects under the immiscible heading. No flue gas projects have been reported as started since 1977 and, therefore, are not included in this report.

Carbon dioxide injection (miscible and immiscible) projects are the second most popular, following polymer flooding, in terms of project starts since the price of oil peaked in 1981. The major oil companies have committed large sums of money to developing carbon dioxide sources and are thereby committed to using this gas.

Miscible Flooding

The miscible recovery process involves the injection of a fluid (usually a gas at surface conditions) which at reservoir conditions is mutually soluble with reservoir oil. Gases used include hydrocarbons, carbon dioxide, flue gas, and nitrogen. Most recent starts use carbon dioxide. Most nitrogen projects are considered to be immiscible or only partially miscible and are, therefore, discussed with the immiscible projects.

The main trends seen in table 10 and figure 9, carbon dioxide miscible projects, are the decrease in project starts since 1980-81 and the increase in major oil company participation since 1982. Most of these projects are in the Permian Basin of West Texas and New Mexico which is now the world leader in CO_2 EOR.[3] Project areas range from 25 to 16,000 acres, and as discussed under polymer flooding, are only shown to provide an estimate of project size. Project depth appeared to be getting shallower, until 1986. *The Oil and Gas*

Journal[3] reports that only 9 of the 43 projects listed as planned in 1986 survived (five were started and four postponed). Several planned deep projects in Louisiana and Mississippi were canceled. Oil production[3] from miscible CO_2 projects increased from 28,440 BOPD in 1986 to 64,190 BOPD early in 1988. No new projects were reported as started in 1987; however, five are reported as planned for 1988.[3]

Hydrocarbon injection project starts (table 11) were high in 1981 when the price of oil peaked, as would be expected, but they peaked in 1983. The reason for this peak is unknown; it seems unrelated to the price of natural gas which peaked in 1984 (average wellhead price). Oil production[3] from this process decreased from 33,770 BOPD in 1986 to an estimated 25,940 BOPD in 1988. Production should increase as the projects started in 1983 begin contributing. Arco's Prudoe Bay Alaska project started in December 1982 is expected to be a major contributor for this process. No trends were seen in the reservoir characteristics shown in table 11.

Immiscible Flooding

Although some immiscible projects use nitrogen or flue gas, most use carbon dioxide at pressures below minimum miscibility. These projects include cyclic (huff 'n' puff), gas drive, and gas-cap injection in dipping reservoirs. Total immiscible production was estimated to be 8,000 BOPD in 1984 and 20,000 BOPD in 1986 and 1988.

Carbon dioxide immiscible projects are summarized in table 12. As with polymer projects, a peak in starts occurred in 1983, 2 years after oil prices peaked. These projects require considerable planning and long lead times, which may have caused some of this lag. Another peak in project starts occurred in 1986; most of these are Texaco projects in Louisiana, most of which were later canceled. Data in the table show a definite increase in both average depth and API gravity, which increases the chances of success.

Almost all of these projects were major oil company starts, and most were in sandstone. Project areas vary widely and are based on too few data and influenced by operator perception as discussed under polymer flooding. Leaving out three large projects (one in 1981, 1982, and 1985) would leave data indicating that project size is becoming smaller. Many new Louisiana offshore projects which usually have an area of less than 100 acres conform to the smaller project trend. Most immiscible projects are in Louisiana and Texas.

Information on nitrogen injection projects is summarized in table 13. The number of project starts peaked in 1981 when the price of oil peaked. Almost all of these projects were started by major oil companies. All of the projects started since 1981 have been applied for the recovery of very light oil (API gravity greater than 46), which lowers the risk for this process.

MICROBIAL PROJECTS

Microbial enhanced oil recovery (MEOR) is a new category for the DOE EOR Project Database. Interest in this process is currently very high. NIPER has collected information on more than 40 projects worldwide. Ten of these are in the United States but only four of these had enough information available to be included in the EOR Project Database. Major oil companies were associated with only 2 of the 10 projects. The high current interest is shown by the start dates for these projects, two in the fifties, two in the seventies, three in 1986, and three in 1987. This process is still in the research stage with only two of the projects large enough to be commercial. Two of the projects are aerobic, seven are anaerobic, and one is unknown.

Reservoir characteristics for these projects are all very similar. Most are sandstones, only one limestone, at an average depth of 1,800 ft (deepest 2,600 ft) having an API oil gravity between 34 and 40.

OTHER NOVEL PROJECTS

This category includes such processes as electro-osmosis and oilfield mining. These are very high-risk processes, and few will be started in this period of declining oil prices. Data on one new mining project were found for 1985. Interest also seems to be increasing in horizontal drilling; however, information was too vague to be included in the EOR Project Database.

DISCUSSION

Although EOR is down it is not out, only temporarily delayed. New project starts for 1987 are extremely low. However, plans for 1988 are encouraging.[3] EOR research and technology advances will continue to lower costs,[6] making EOR in the future one of the cheapest sources of new oil reserves. Although oil price is the most important factor affecting new EOR projects (Fig. 1), other factors can overcome it. The second most important factor is past economic success. This is characteristic of steamdrive, polymer flooding, and carbon dioxide injection projects which continue to be implemented even with low oil prices. A third factor is momentum, exemplified by the carbon dioxide projects for which oil companies have committed large sums of money to pipelines and gas supplies.

The recent decline in oil price has caused layoffs, bankruptcies, and the shutting-in of oil wells. Many of the projects scheduled to start in 1986 and 1987 were canceled or postponed, especially polymer and immiscible gas.[3] Table 14 summarizes EOR project starts by year. In 1980 and 1981, miscible projects were the most popular, and since then polymer projects have been most popular. In 1986, steam and immiscible projects appear to be increasing dramatically in the number of projects started. Taking into consideration that the numbers for 1986 include many projects which were canceled or postponed, the numbers are down for 1986 and down dramatically for 1987. The

economics of each project are being very carefully studied, and only those with acceptable economic risk will be started. This results in almost no change in the characteristics of the projects in a process. In other words, the trend in reservoir characteristics is toward those of earlier successful projects.

The decline in the number of new projects started means that future EOR production will be down. In 1987, overall EOR production was up only 5.4% over 1986. Thermal projects' production, which accounts for about three-fourths of EOR production, was down 3.1%.[3]

Microbial enhanced oil recovery had its first significant project starts in 1986 and 1987. As oil production increases from these pilots, this technology could expand rapidly.

Polymer flooding continues to be the most popular chemical process mainly because of its low cost per barrel of oil recovered. The number of new projects peaked in 1983 and 1984, 2 or 3 years after the price of oil peaked.

States are still considering tax incentives and other methods of encouraging EOR such as the recently suggested state bond issues. The DOE's support for EOR education and research and the resulting technical advances are important incentives. As research finds and develops more economical EOR techniques and government continues encouragement, the importance of EOR will increase.

CONCLUSIONS

The downward trend in EOR project starts has hopefully reached bottom with only 10 new projects started in 1987. The strong relationship between oil price and the number of project starts continues. Until the price of oil increases or significant research advances are made in oil recovery, EOR production will remain low.

Polymer projects have been the most popular EOR process for the past 6 years (1982-1987). The trend to deeper, hotter projects indicates companies are using more thermally stable polymers.

The recent (1986-1987) interest in microbial EOR is encouraging.

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TABLE 1. - Average U.S. crude oil prices[1]

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Wellhead price, $/bbl	12.64	21.59	31.77	28.52	26.19	25.88	24.09	12.51	15.41	14.85
Refiners' cost, $/bbl	14.27	24.23	34.33	31.22	28.87	28.53	26.66	14.82	17.77	16.95

[1] EIA Annual Energy Review 1987

TABLE 2. - Distribution of projects in the EOR Database by state

State	Projects	State	Projects	State	Projects	State	Projects
Alaska	5	Indiana	3	Mississippi	16	Pennsylvania	6
Alabama	7	Kansas	29	Montana	19	South Dakota	1
Arkansas	11	Kentucky	10	North Dakota	8	Texas	286
California	456	Louisiana	99	Nebraska	6	Utah	10
Colorado	8	Michigan	1	New Mexico	22	West Virginia	8
Florida	2	Missouri	6	Oklahoma	113	Wyoming	119

TABLE 3. - Steam project starts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Year Started	Majors #/Total	Area, acres	Avg depth	Range depth	Avg API	Range API	Avg porosity	Range porosity
1980	14/19	292	1140	120-2700	13.9	8-24	30.6	20-42
1981	32/40	107	1436	350-4500	14.3	2-30	29.6	18-37
1982	20/24	54	1704	500-3500	13.8	8-30	30.3	7.5-37
1983	13/18	121	1164	300-2550	12.5	11-16	32.5	31-38
1984	15/21	104	1303	350-1900	13.6	11-18	33.1	29-37
1985	15/21	39	1490	200-4400	13.3	8-22	31.7	16-40
1986	18/22	207	1486	400-3300	14.3	10-21	33.0	28-35
1987	4/5	168	1210	500-3000	14.1	11-21	35.0	34-36

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Average reported porosity.
(8) Range of porosities.

TABLE 4. - In situ combustion project starts

Year Started	(1) Majors #/Total	(2) Area, acres	(3) Avg depth	(4) Range depth	(5) Avg API	(6) Range API	(7) #SS/ Proj	(8) Avg porosity	(9) Range porosity
1980	6/10	134	877	150-2350	23.3	14.7-32	10/0	23.2	18-36.9
1981	3/4	43	1283	950-1500	19.9	15-29	3/0	28.4	19.7-33.1
1982	1/2	112	1100	1100	21.0	21	---	38	38
1983	---	--	----	--------	----	-----	---	----	----
1984	---	--	----	--------	----	-----	---	----	----
1985	1/2	17	2650	500-4800	10.5	18-21		33	28-38
1986	0/1	600	1250	1250	11.5	11.5	1/0	----	----

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 5. - Unconventional steam project starts

Year Started	(1) Majors #/Total	(2) Area, acres	(3) Avg depth	(4) Range depth	(5) Avg API	(6) Range API	(7) #SS/ Proj	(8) Avg porosity	(9) Range porosity
1980	2/5	112	2773	2100-3200	8.6	2-14	5/0	29.6	29-30.1
1981	6/8	87	3175	2701-4500	21.6	10-47	7/0	30.2	18-35
1982	3/3	101	2675	2575-2850	14.7	13-17	3/0	28.5	27-30
1983	1/1	80	3400	3400	11	11	1/0	30	30
1984	1/1	--	3800	3800	22	22	---	31	31
1985	1/1	2240	7500	7500	28.5	28.5	0/1	4.5	4.5

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 6. - Surfactant project starts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year Started	Majors #/Total	Area, acres	Avg depth	Range depth	Avg API	Range API	#SS/ Proj	Avg porosity	Range porosity
1980	9/20	74	3677	510-7983	32.2	21-43	17/1	21.8	14.7-31.8
1981	3/3	38	3187	1600-5060	37	32-40	2/1	18.3	11/24
1982	2/3	---	1400	950-1800	37.7	29-45	---	20.7	20-21
1983	1/1	200	2317	--------	37	---	1/0	19.0	-------
1984	1/1	45	3950	--------	27	---	1/0	28.8	-------
1985	2/3	3	3133	900-4600	29.3	20-39	2/0	16.2	14-20.6

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 7. - Polymer project starts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year Started	Majors #/Total	Area, acres	Avg depth	Range depth	Avg API	Range API	#SS/ Proj	Avg porosity	Range porosity
1980	6/19	869	4046	1500-7301	32.8	16-43	13/3	16.0	6.0-31.3
1981	18/34	1344	3293	480-8300	33.6	12-49	10/2	18.0	7.1-41.9
1982	25/34	1274	4159	550-12000	34.1	20-47	12/2	17.8	4.1-35
1983	42/53	1310	4571	999-11400	34.4	22-48	14/8	16.6	7.7-30
1984	45/54	1181	4587	775-8700	32.2	17-42	29/13	17.4	7.7-42.3
1985	20/39	2242	4904	630-9400	33.5	20-47	25/5	17.5	9.6-28
1986	25/36	2444	4514	700-13000	32.5	16-46	5/1	17.0	8.5-30.1
1987	0/5	123	5129	800-9515	27.0	20-32	5/0	18.6	14.9-23

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 8. - Data on temperature and salinity of polymer project starts

Year	No. of Projects	No. Reporting	Temperature		
			Average, °F	High, °F	Low, °F
1980	19	18	141	217	93
1981	34	27	98	175	70
1982	32	28	114	190	65
1983	52	38	112	190	80
1984	49	45	122	200	78
1985	37	32	134	240	83
1986	36	8	123	165	95

Year	No. of Projects	No. Reporting	Salinity, total dissolved solids		
			Average, ppm	High, ppm	Low, ppm
1980	19	12	42,500	195,000	238
1981	34	8	57,600	123,000	502

TABLE 9. - Alkaline project starts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year Started	Majors #/Total	Area, acres	Avg depth	Range depth	Avg API	Range API	#SS/ Proj	Avg porosity	Range porosity
1980	3/13	1364	3400	405-10130	32.3	16-43	9/4	18.8	13.4-31
1981	3/9	213	5373	740-10250	29.8	18-42	7/1	24.6	13-32.1
1983	0/1	1100	4200	4200	39.0	---	---	17.0	17.0
1986	2/2	3	5675	5650-5700	28.5	25-32	---	31.0	31.0

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 10. - Carbon dioxide miscible project starts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year Started	Majors #/Total	Area, acres	Avg depth	Range depth	Avg API	Range API	#SS/ Proj	Avg porosity	Range porosity
1980	14/26	1581	5679	1000-10400	35.7	14-45	11/9	17.0	9-37
1981	15/28	2430	6030	1300-11530	36.4	14-44	13/11	16.9	6-37
1982	4/10	991	7220	2300-13000	34.2	14-49	5/1	17.1	8.5-27
1983	4/6	6169	6724	4900-8500	38.8	33-43	1/3	14.0	8-30
1984	7/8	3936	6515	5050-13275	33.9	28-45	1/6	13.8	6.4-30
1985	8/11	5094	5981	1270-10750	36.8	20-41	4/5	16.5	7.7-29
1986	6/8	3410	6438	800-12000	35.5	28-46	1/2	13.0	10-15

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 11. - Hydrocarbon project starts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year Started	Majors #/Total	Area, acres	Avg depth	Range depth	Avg API	Range API	#SS/ Proj	Avg porosity	Range porosity
1980	0/2	388	1750	500-3000	29.5	18-41	2/0	25.0	----
1981	5/6	974	10739	1200-16150	38.8	35-48	5/1	25.6	16-31
1982	0/2	640	8900	8800-9000	32.6	25-40	0/1	16.2	10-22
1983	8/8	6.5	6553	4300-11270	32.6	19-43	3/0	26.9	9-33
1984	2/2	53	8250	8000-8500	34.5	33-36	2.0	29.5	29-30
1985	3/3	849	5050	4500-5750	31.3	29-33	1/2	17.0	9-30
1986	1/1	15360	6000		24.0		1/0	22.0	
1987	1/1	13500	8800		27.0		1/0	22.0	

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 12. - Immiscible carbon dioxide project starts

Year Started	(1) Majors #/Total	(2) Area, acres	(3) Avg depth	(4) Range depth	(5) Avg API	(6) Range API	(7) #SS/ Proj	(8) Avg porosity	(9) Range porosity
1980	----	--	----	--------	--	-----	---	---	----
1981	1/1	--	12000	--------	47.0	-----	---	5.0	----
1982	4/4	766	5184	3785-9000	23.7	23-25	1/0	27.0	25-30
1983	15/16	540	4948	2600-10000	25.6	14-39	2/0	25.8	13-31
1984	10/11	231	6745	1300-10200	32.9	14-47	5/0	21.1	8-31
1985	11/11	2106	8350	1400-13125	33.7	26-42	6/1	22.4	4.5-32
1986	20/21	264	9728	5200-14000	37.0	31-45	20/0	22.0	----

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 13. - Nitrogen project starts

Year Started	(1) Majors #/Total	(2) Area, acres	(3) Avg depth	(4) Range depth	(5) Avg API	(6) Range API	(7) #SS/ Proj	(8) Avg porosity	(9) Range porosity
1980	2/30	893	6900	5800-11000	37.7	21-46	1/1	16.8	12-27
1981	5/5	5449	9828	7350-15552	43.8	38-51	1/2	9.2	4-14
1982	1/1	5120	9000	--------	60.0	---	0/1	5.5	---
1983	1/1	1500	12000	--------	46.0	---	1/0	11.0	---
1984	1/1	23279	18500	--------	60.0	---	0/1	14.2	---
1985	1/1	600	15565	--------	48.0	---	0/1	12.0	---

(1) Number of projects started by major oil companies/total EOR projects started.
(2) Average reported area in acres.
(3) Average depth to top of producing formation in feet.
(4) Shallowest project - deepest project, ft.
(5) Average API gravity.
(6) Range of API gravities.
(7) Number of projects reported in sandstone/number in limestone.
(8) Average reported porosity.
(9) Range of porosities.

TABLE 14. - Summary of EOR project starts each year by process

	1980	1981	1982	1983	1984	1985	1986	1987
Conventional Steam	19	40	24	18	21	21	22	5
In Situ Combustion	10	4	2	0	0	2	1	0
Unconventional Steam	5	8	3	1	1	1	0	1
Surfactant (Micellar-polymer)	20	3	3	1	1	3	0	0
Polymer	19	34	34	53	54	39	36	5
Alkaline	13	9	0	1	0	0	2	0
Carbon Dioxide Miscible	26	28	10	6	8	11	7	0
Hydrocarbon Gas	2	6	2	8	2	3	1	1
Carbon Dioxide Immiscible	0	1	4	16	11	11	21	0
Nitrogen Gas	3	5	1	1	1	1	0	0
Microbial projects	--	--	--	--	---	---	3	1
Total	117	138	81	104	99	90	93	13

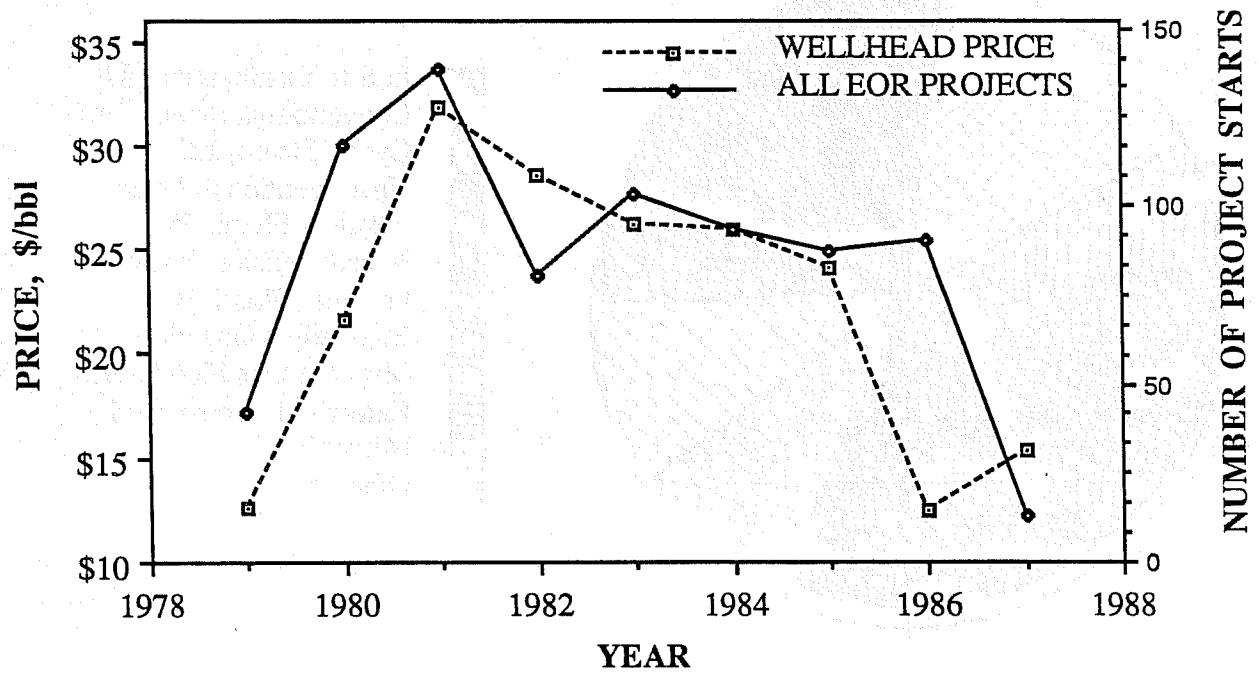

FIGURE 1. - Comparison of wellhead oil price with total EOR project starts between 1979 and 1987.

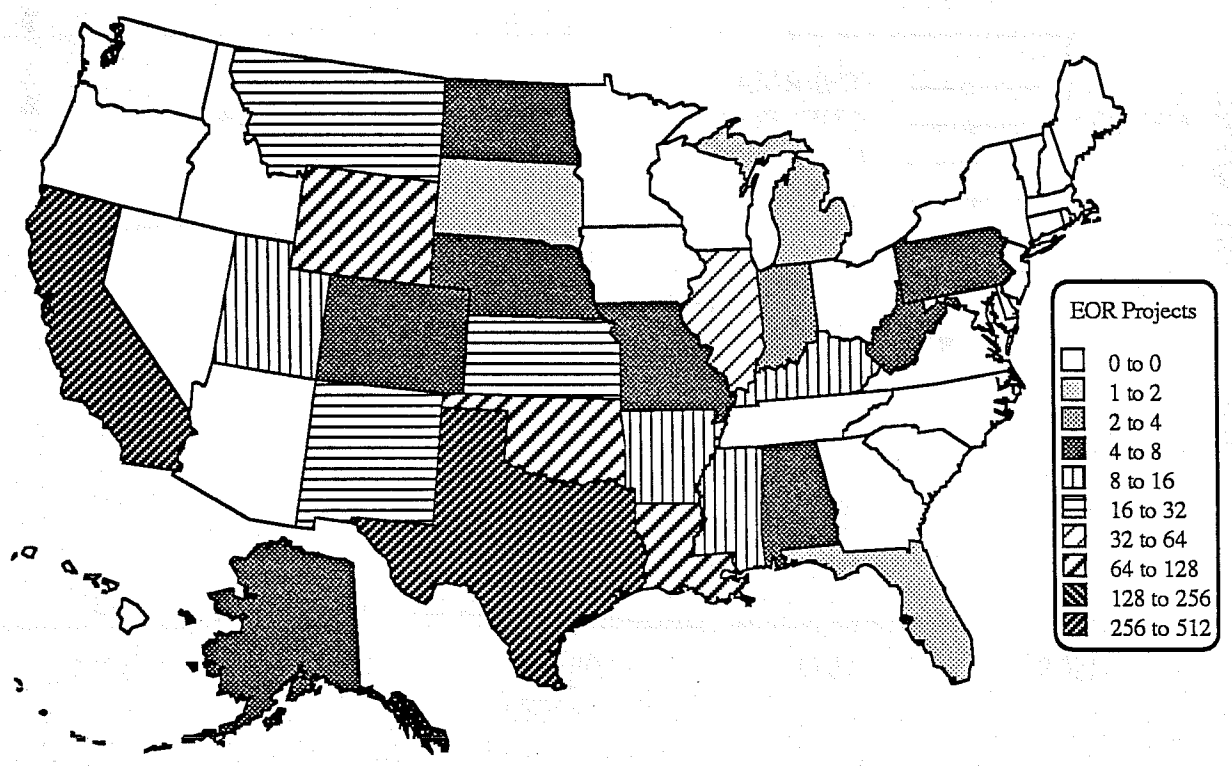

FIGURE 2. - Map showing distribution of EOR projects by state.

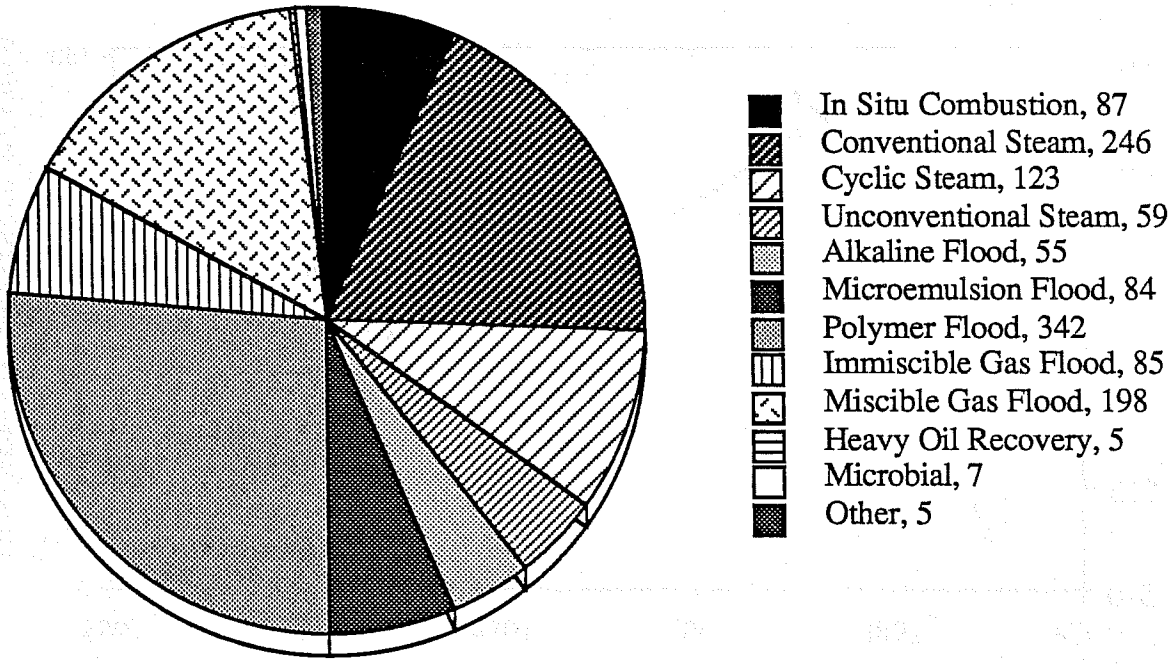

FIGURE 3. - Distribution of EOR projects in the DOE Data Base by process.

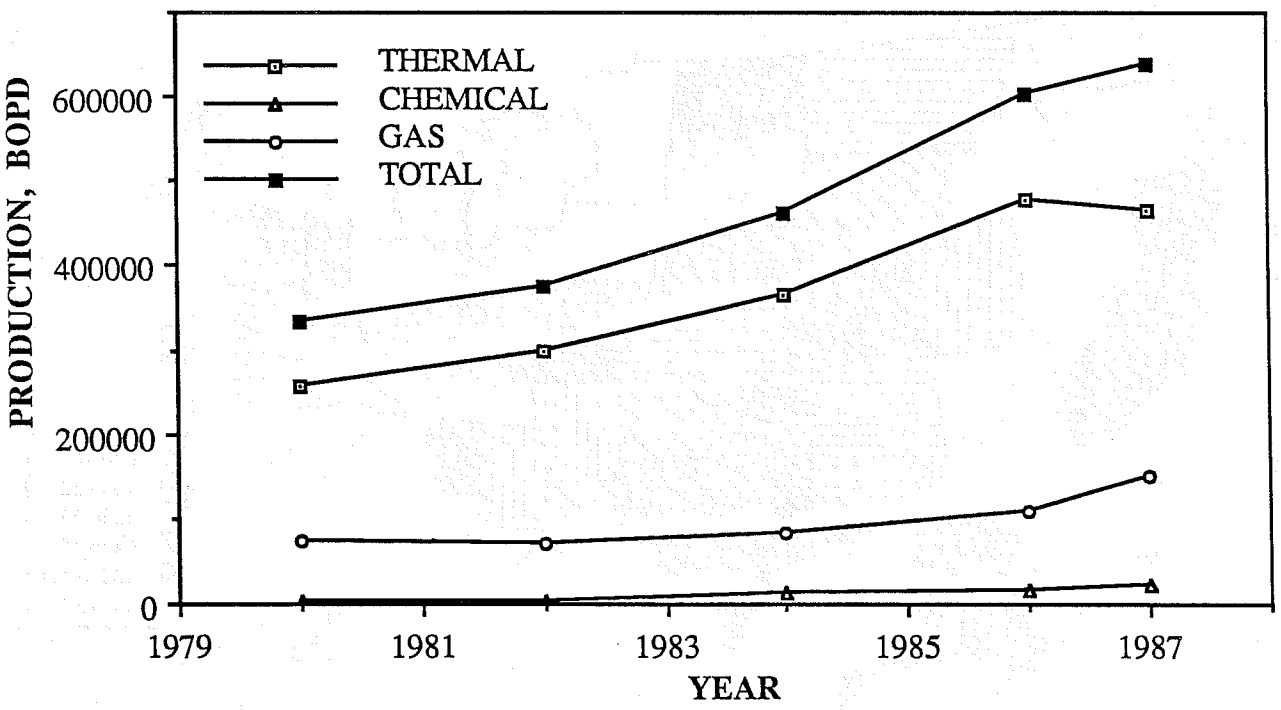

FIGURE 4. - U.S. EOR daily production rate by category (note, value for 1988 is a prediction[3]).

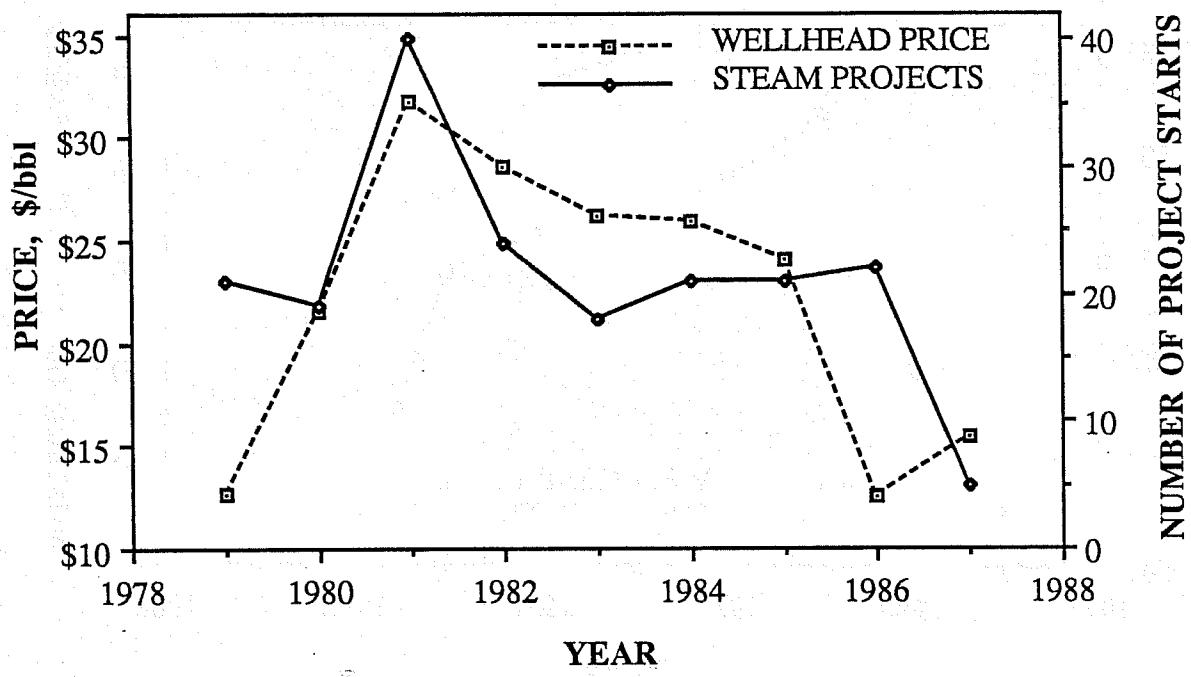

FIGURE 5. - Comparison of conventional steamflooding project starts with wellhead price between 1979 and 1987.

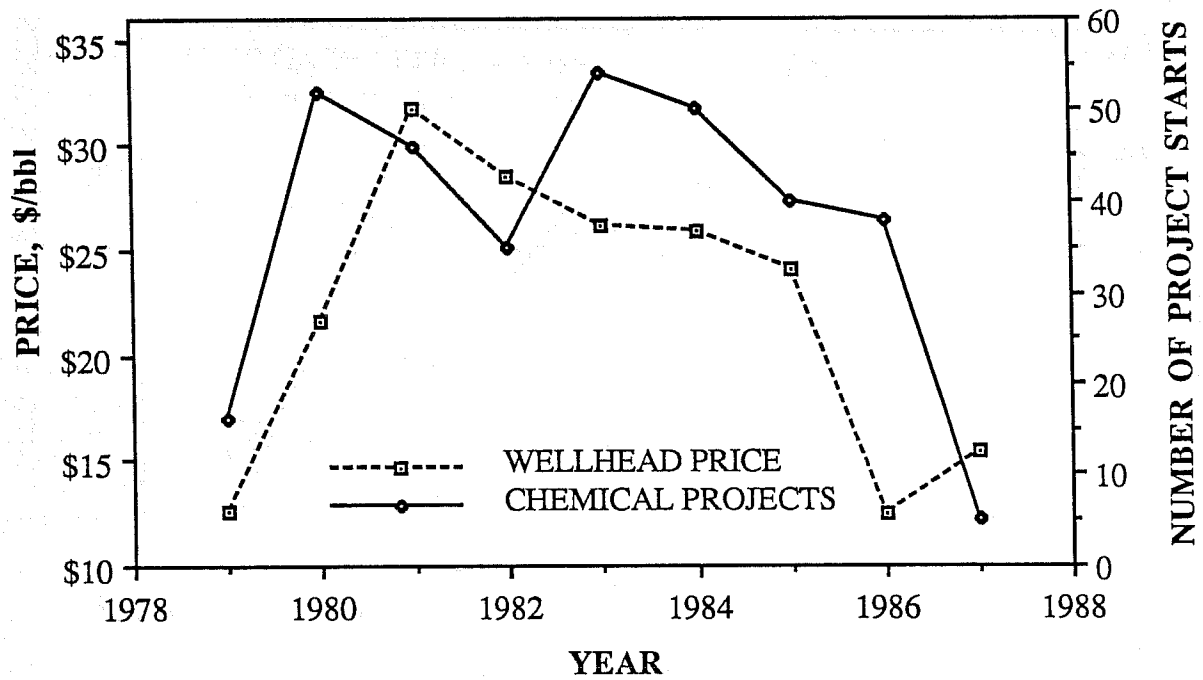

FIGURE 6. - Comparison of chemical EOR project starts with wellhead oil price between 1979 and 1987.

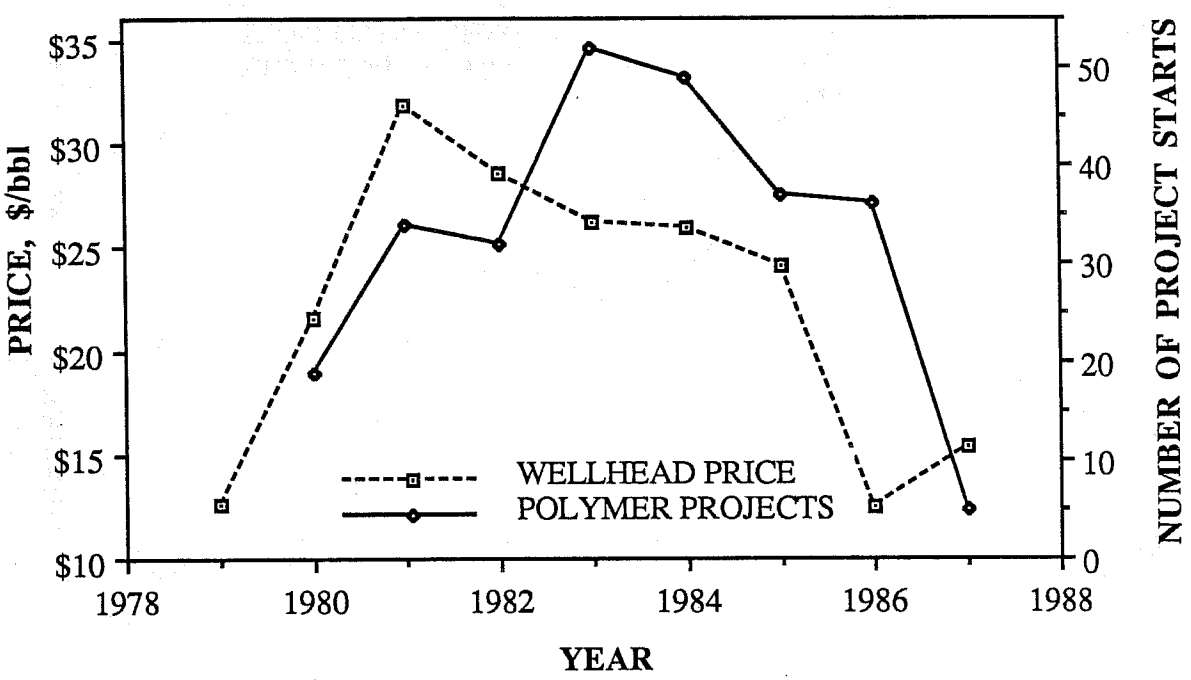

FIGURE 7. - Comparisons of polymer flood starts with wellhead oil price between 1979 and 1987.

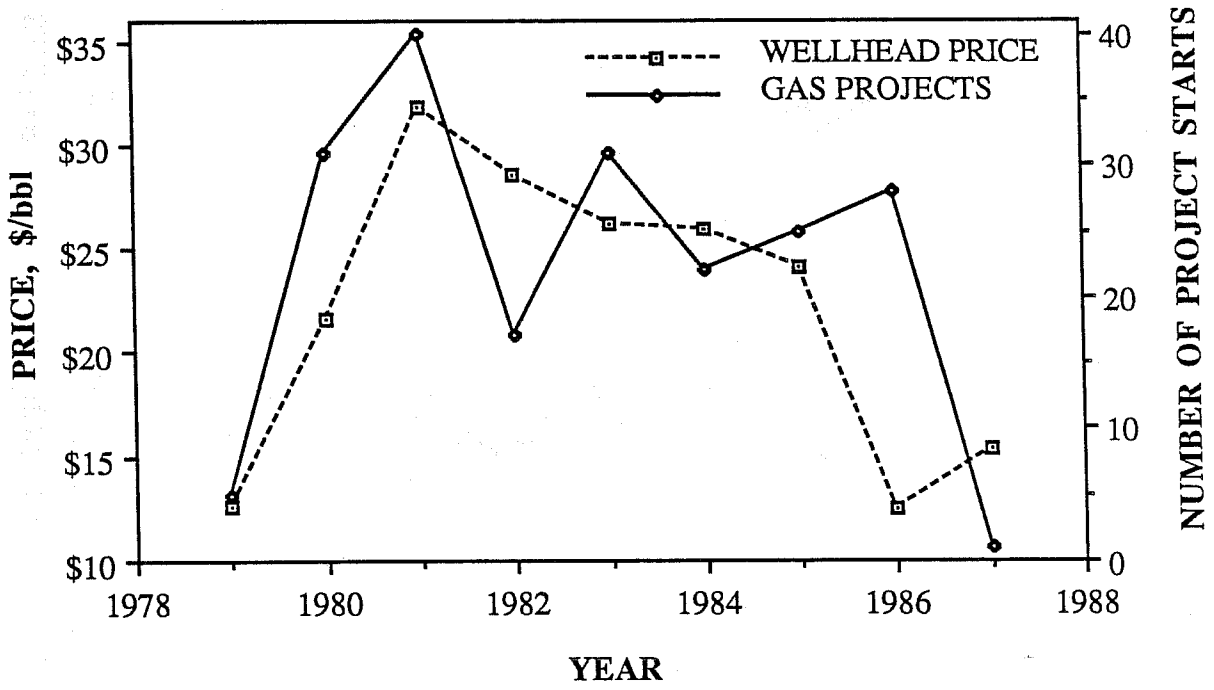

FIGURE 8. - Comparison of gas injection project starts with wellhead oil price between 1979 and 1987.

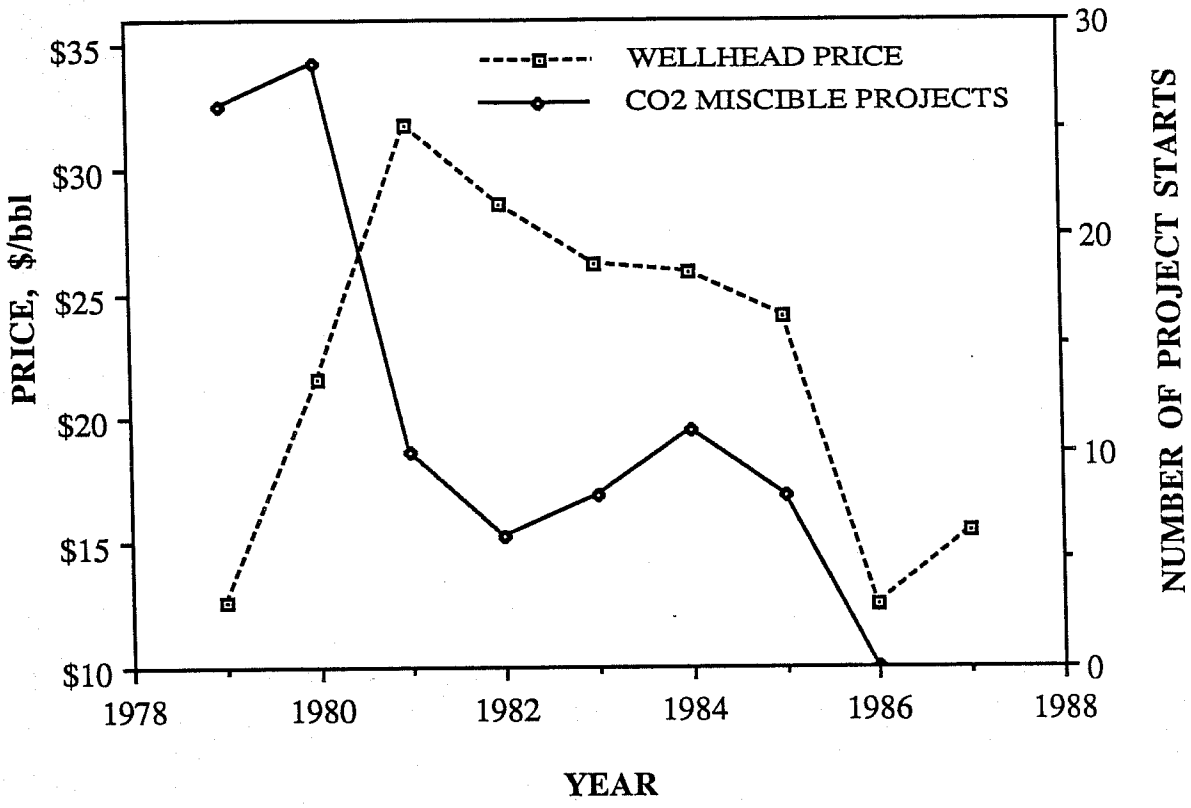

FIGURE 9. - Comparison of carbon dioxide miscible flood project starts with wellhead prices between 1979 and 1987.