CHAPTER V

RESULTS AND DISCUSSION

This chapter presents the performance of gas condensate reservoirs simulated under different production/injection scenarios. The results are discussed in terms of production life, oil and gas production volume, and economics.

In this study, ten different hydrocarbon compositions were simulated for two types of production: natural depletion and gas recycling. Gas production rate economic limit of 100 MSCF/D and bottomhole pressure of 500 psia were applied for production well control. The details of the two types of production are explained as follows:

1. Natural depletion of gas-condensate reservoirs

The gas condensate reservoirs were developed with natural depletion. The well is located at the center of reservoirs which is shown in Figure 5.1.

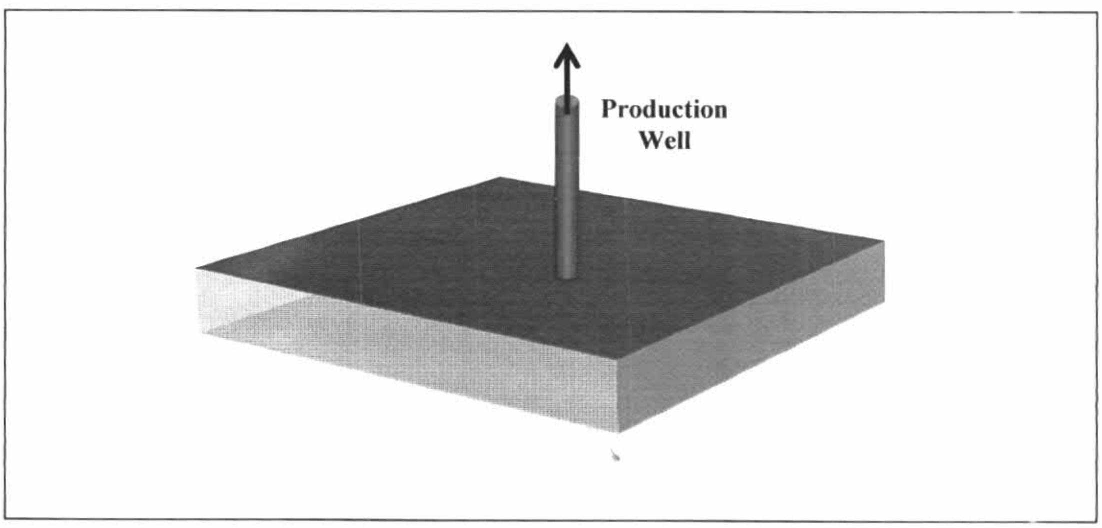


Figure 5.1: A production well in gas-condensate reservoirs when produced with natural depletion.

2. Production of gas-condensate reservoirs with gas cycling

In this scenario, the gas-condensate reservoirs are developed with produced gas cycling process. There are two wells. The first well is the producer and another well is the injector for pressure maintenance. The schematic for this scenario is shown in Figure 5.2.

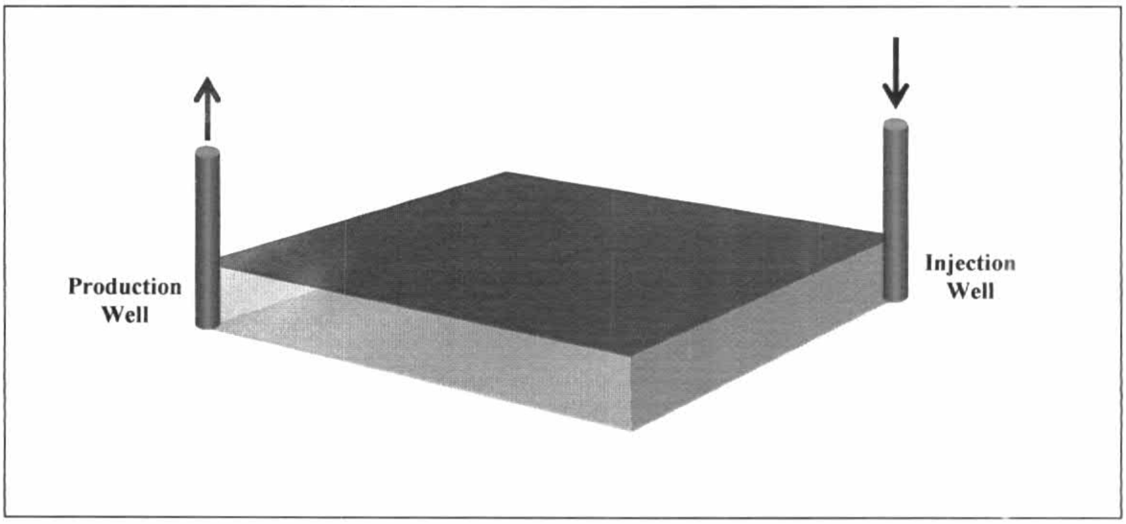


Figure 5.2: A production well and an injection well in gas-condensate reservoirs for production with gas cycling.

5.1 Production of Gas-Condensate Reservoirs with Natural Depletion

Natural depletion is the method which is applied in gas condensate reservoirs in the first set of simulation. In this simulation, ten different hydrocarbon compositions are used to investigate the effect of composition on recovery performance. The gas production rate is fixed at 5,000 MSCF/D and kept constant as long as the reservoirs can sustain for each set of component. The bottom hole pressure declines as the production of gas-condensate reservoirs keeps onwards. At a certain reservoir condition, the gas production rate drops, and gas is produced till abandonment which is 100 MSCF/D. The gas production rate and oil production rate are shown in Figures 5.3 and 5.4, respectively. The total gas and oil production are shown in Figures 5.5 and 5.6, respectively. Table 5.1 summarizes the cumulative production of gas and oil. Figures 5.7 to 5.9 depict the total gas and oil production as a function of mole percentage of $C_{5+}$and C_{7+} and molecular weight of the composition.

The performance of gas-condensate reservoirs with natural depletion can be summarized as follows:

a) For most cases, both gas and oil productions remain constant for a certain duration before declining except for cases 2 and 8 in which the oil production sharply declines right away after the well is put on production although the gas rate remains constant. This oil rate reduction is caused by the fact that the reservoir pressure falls below the dew point pressure, condensate gas ratio changes, and then gas condenses and is trapped in the reservoirs

b) The total oil production ranges from 18,661 to 63,306 STB while the total gas production ranges from 555 to 595 MMSCF.

c) The total oil production tends to increase respect to mole percentage of $C_{5+}$and C_{7+} and molecular weight of the composition, and so does the total gas production as depicted in Figures 5.7 to 5.9 and Table 5.1.

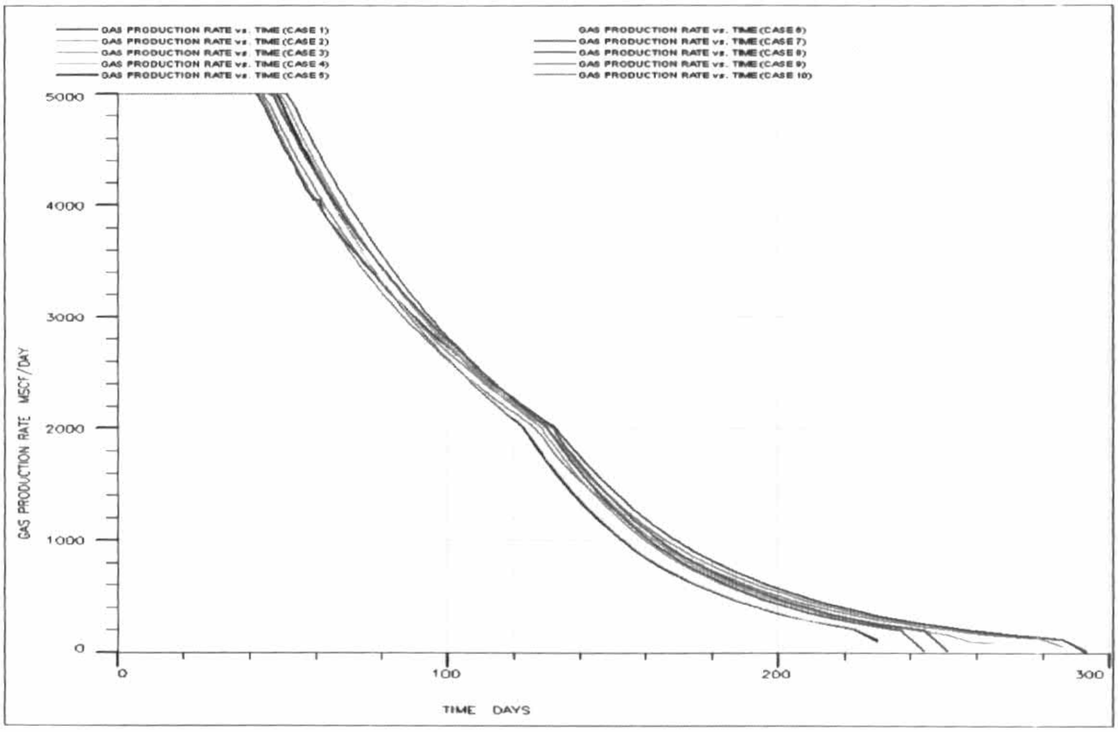


Figure 5.3: Gas production rates (GPR) for production with natural depletion.

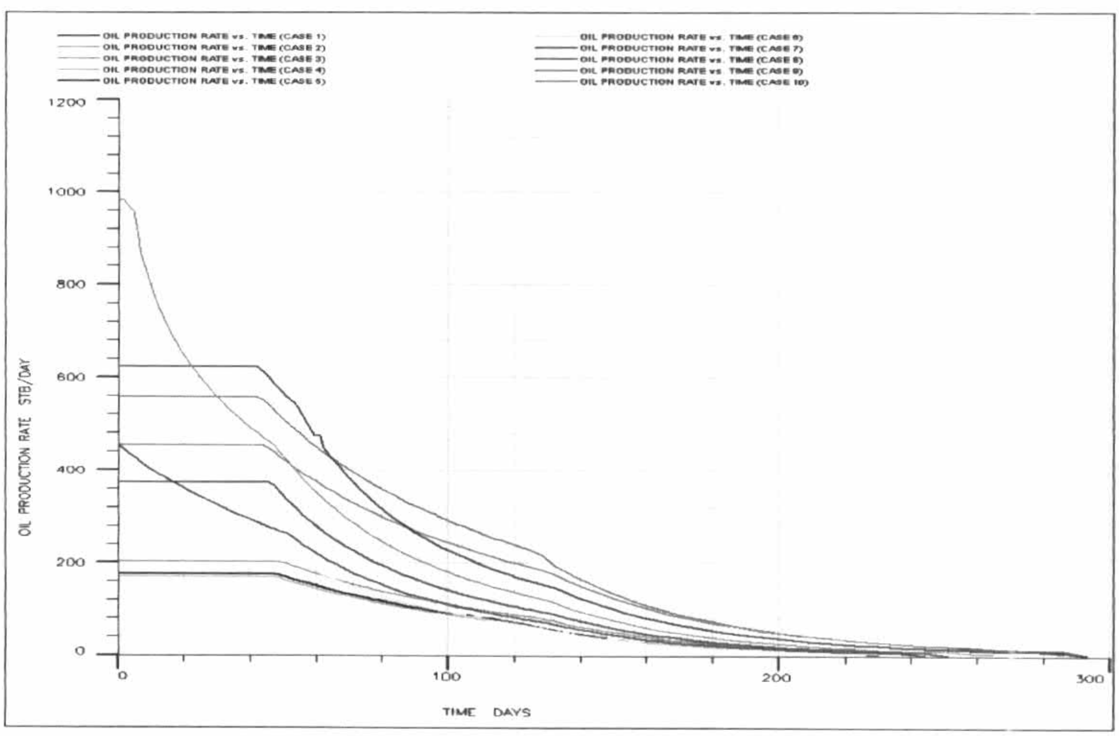


Figure 5.4: Oil production rate (OPR) for production with natural depletion.

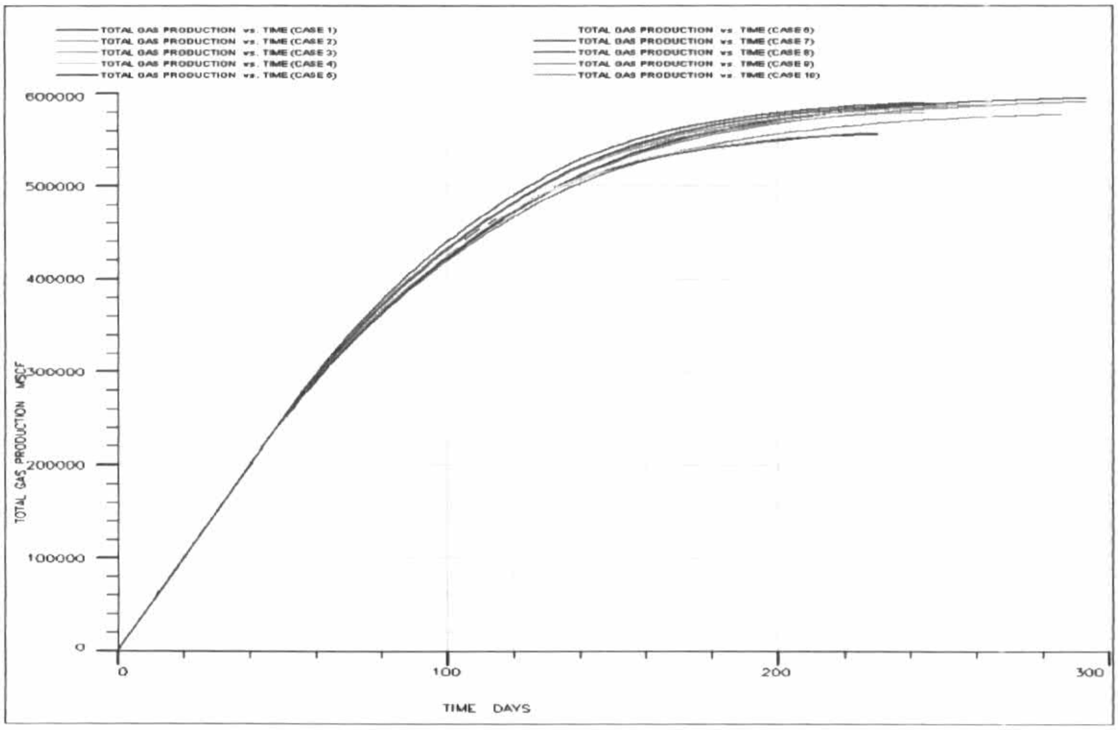


Figure 5.5: Total gas production with natural depletion.

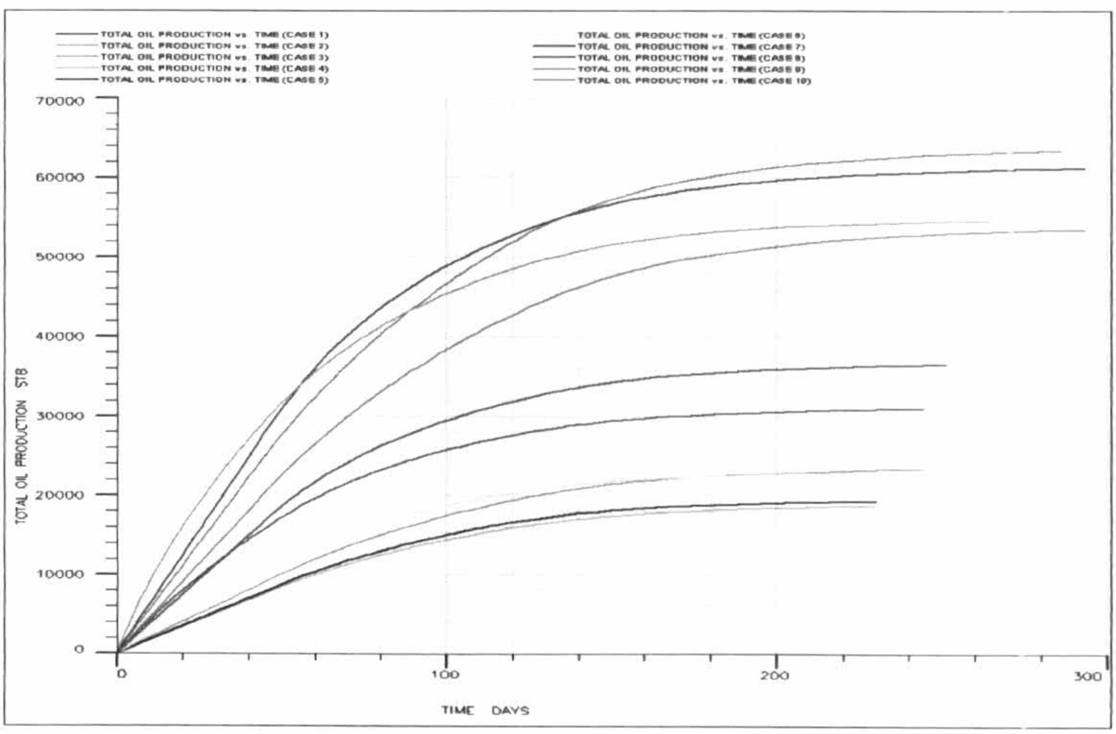
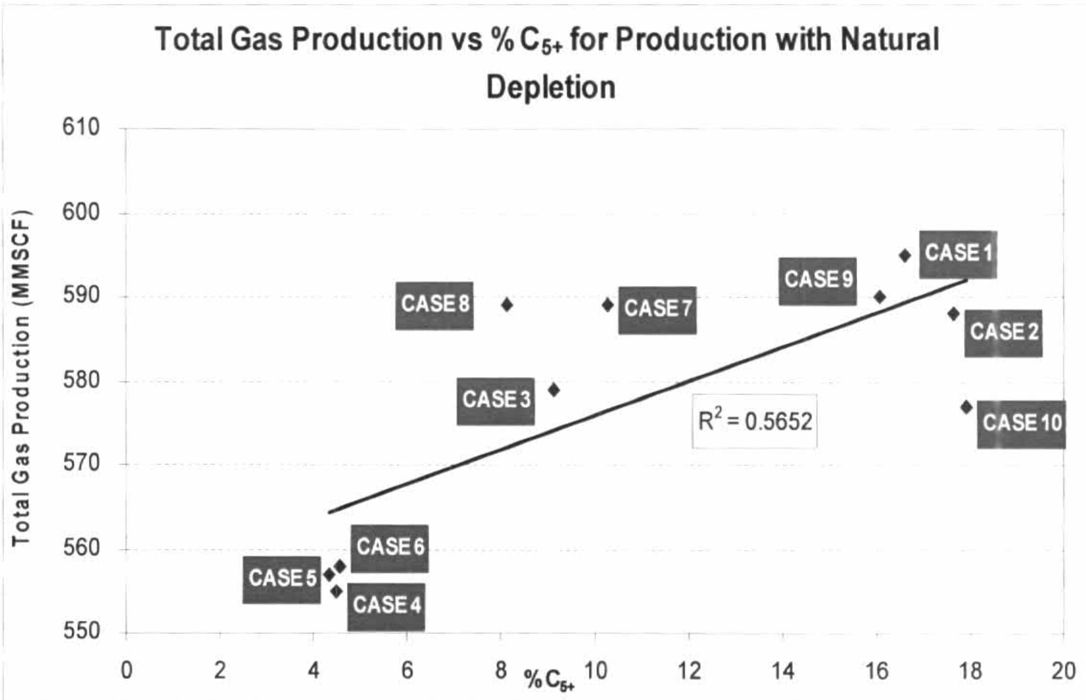


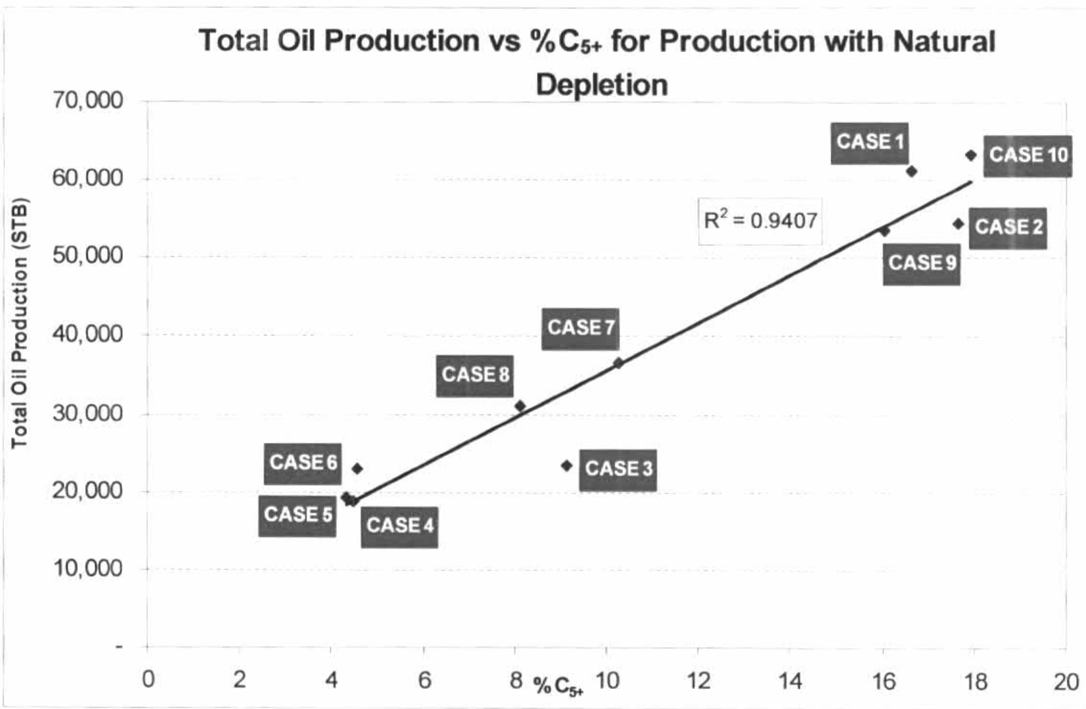
Figure 5.6: Total oil production with natural depletion.

Table 5.1: Total gas production (GPT) and total oil production (OPT) by natural depletion.

#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular Weight	Total gas production (MMSCF)	Total oil production (STB)
1	16.64	6.54	35.60	595	61,126
2	17.66	13.39	46.33	588	54,519
3	9.15	6.56	26.80	579	23,313
4	4.50	3.06	23.19	555	18,661
5	4.35	2.83	22.65	557	19,307
6	4.56	3.26	23.41	558	22,937
7	10.28	5.03	29.87	567	61,548
8	8.14	6.33	31.04	589	30,976
9	16.07	8.85	38.12	590	53,429
10	17.92	10.4	39.10	577	63,306

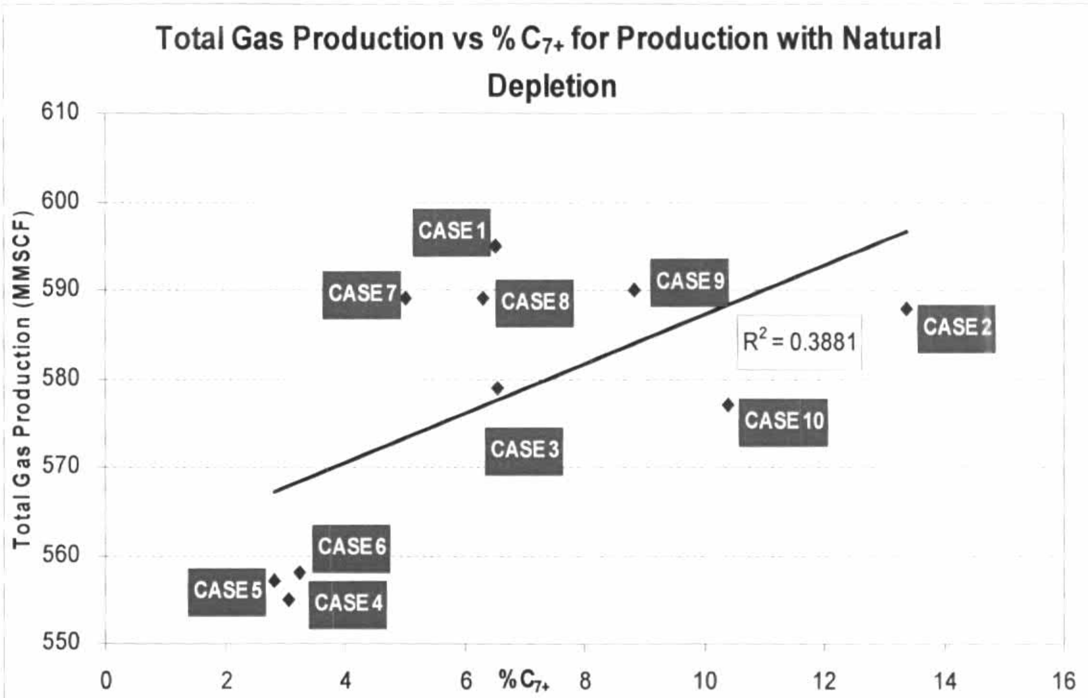


(a) Total gas production (GPT) for production with natural depletion as a function of mole percentage of C_{5+}.

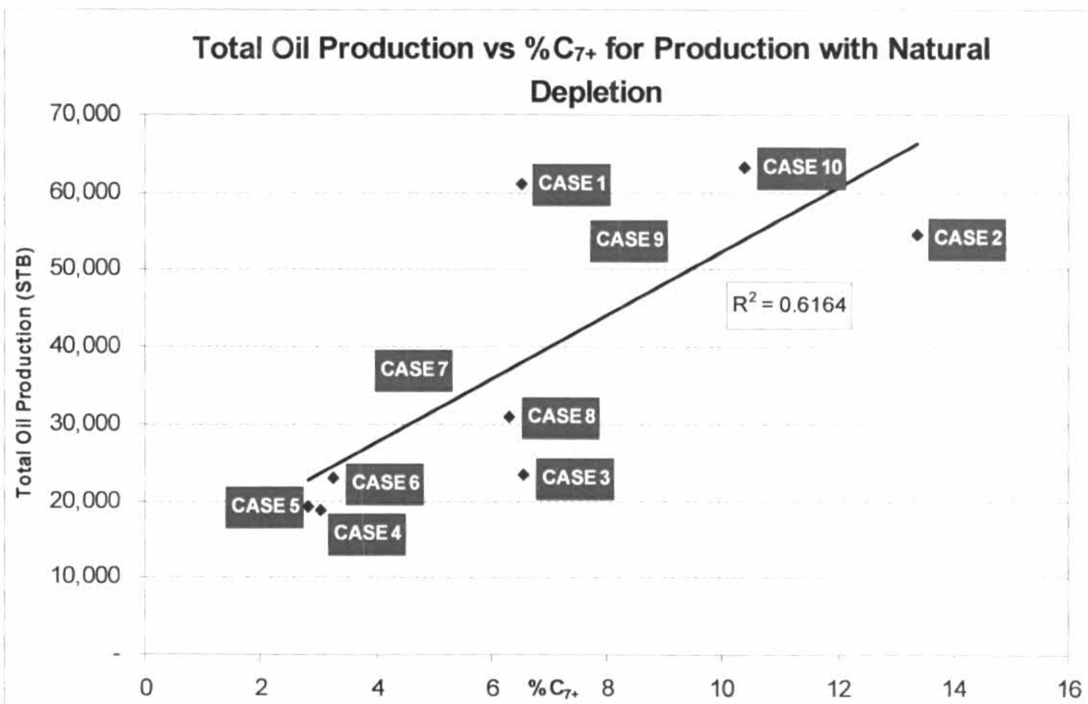


(b) Total oil production (OPT) for production with natural depletion as a function of mole percentage of C_{5+}.

Figure 5.7: Total gas and oil production for production with natural depletion as a function of mole percentage of C_{5+}.

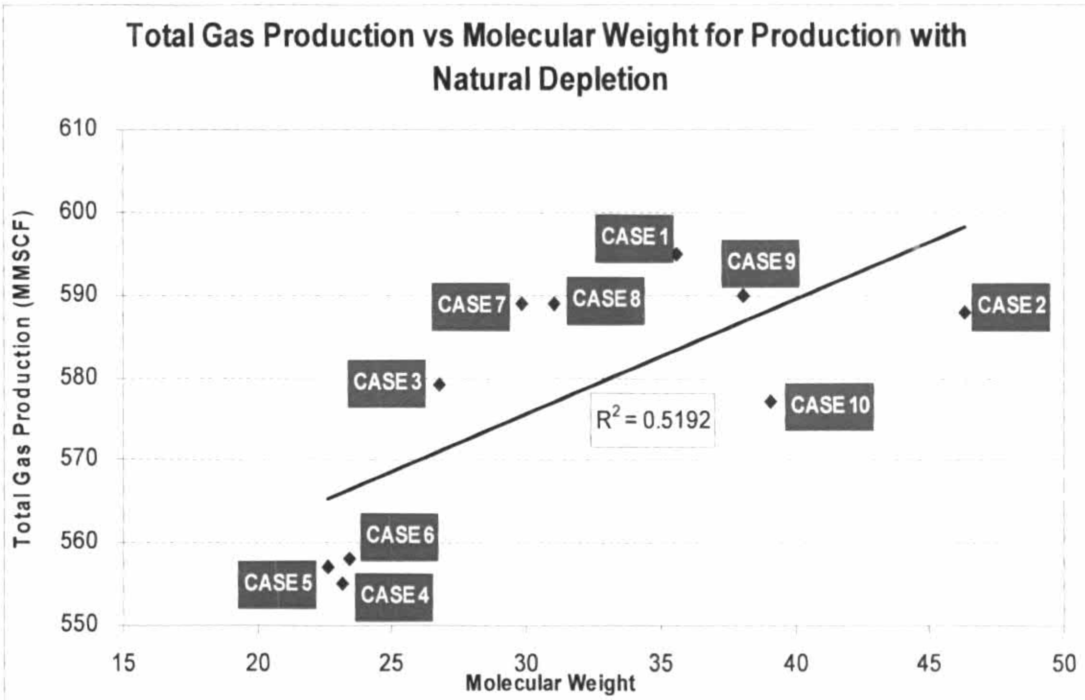


(a) Total gas production (GPT) for production with natural depletion for as a function of mole percentage of C_{7+}.

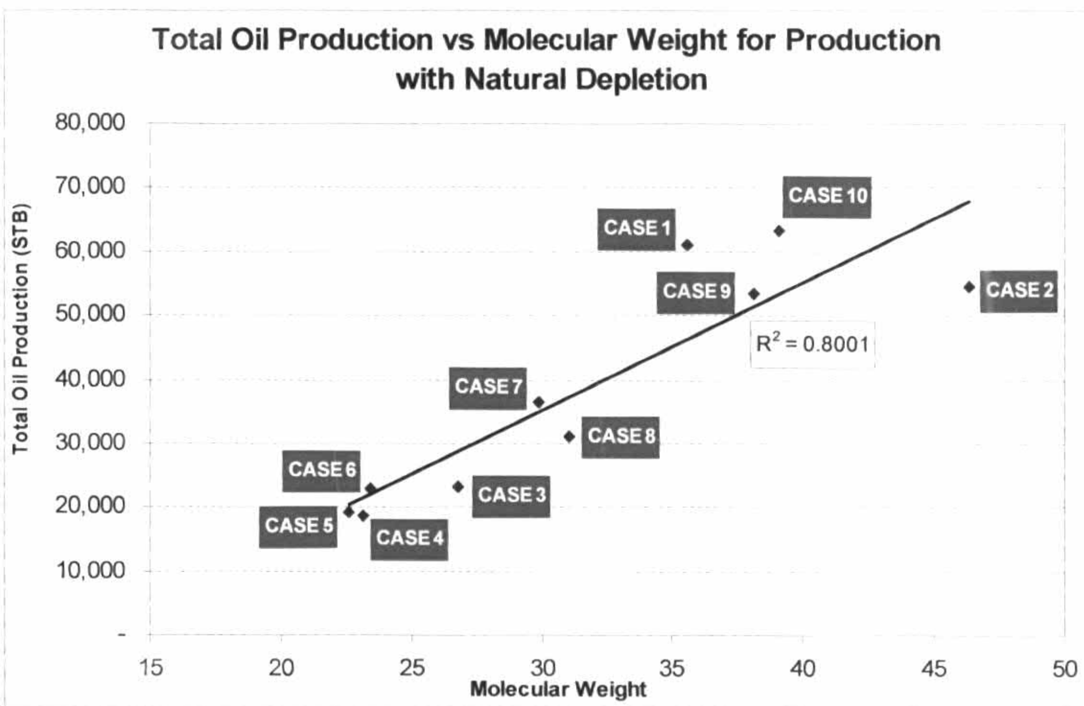


(b) Total oil production (OPT) for production with natural depletion as a function of mole percentage of C_{7+}.

Figure 5.8: Total gas and oil production for production with natural depletion as a function of mole percentage of C_{7+}.



(a) Total gas production (GPT) for production with natural depletion as a function of molecular weight of the composition.



(b) Total oil production (OPT) for production with natural depletion as a function of molecular weight of the composition.

Figure 5.9: Total gas and oil production for production with natural depletion as a function of molecular weight of the composition.

5.2 Economic Analysis for Production of Gas-Condensate Reservoirs with Natural Depletion

The economic analysis for natural depletion scenario is summarized in Table 5.2 and NPV is illustrated in Figures 5.10 to 5.13. All the simulated cases give positive net present values and high internal rates of return. A discount rate of 10% was used in the calculation of NPV.

The economic analysis for production of gas-condensate reservoirs with natural depletion can be summarized as follow:

a) Net present values are positive for all the cases when 10% discount is taken into account. Figures 5.11 to 5.13 show the relationship of NPV as a function of mole percentage of C_{5+} and C_{7+} and molecular weight of the composition. It can be seen that the value of NPV tends to increase when mole percentage of C_{5+} and C_{7+} and molecular weight of the composition increases.

b) All the cases give positive internal rates of return (IRR > 0). The IRR value tends to increase while the pay back period decreases when mole percentage of C_{5+} and C_{7+} and molecular weight of the composition increases as illustrated in Figures 5.14 to 5.17.

Table 5.2: NPV, IRR and Payback period of natural depletion.

#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular Weight	Net Present Value (NPV , US$)	Internal Rate of Return (IRR , %)	Payback Period (Days)
1	16.64	6.54	35.60	5,859,539	1,954	19
2	17.66	13.39	46.33	6,200,802	2,450	14
3	9.15	6.56	26.80	5,107,988	1,120	32
4	4.50	3.06	23.19	2,445,064	893	37
5	4.35	2.83	22.65	2,509,754	915	37
6	4.56	3.26	23.41	2,753,895	1,028	34
7	10.28	5.03	29.87	4,223,341	1,454	26
8	8.14	6.33	31.04	3,625,051	1,368	26
9	16.07	8.85	38.12	6,127,300	1,845	20
10	17.92	10.4	39.10	6,688,813	2,055	19

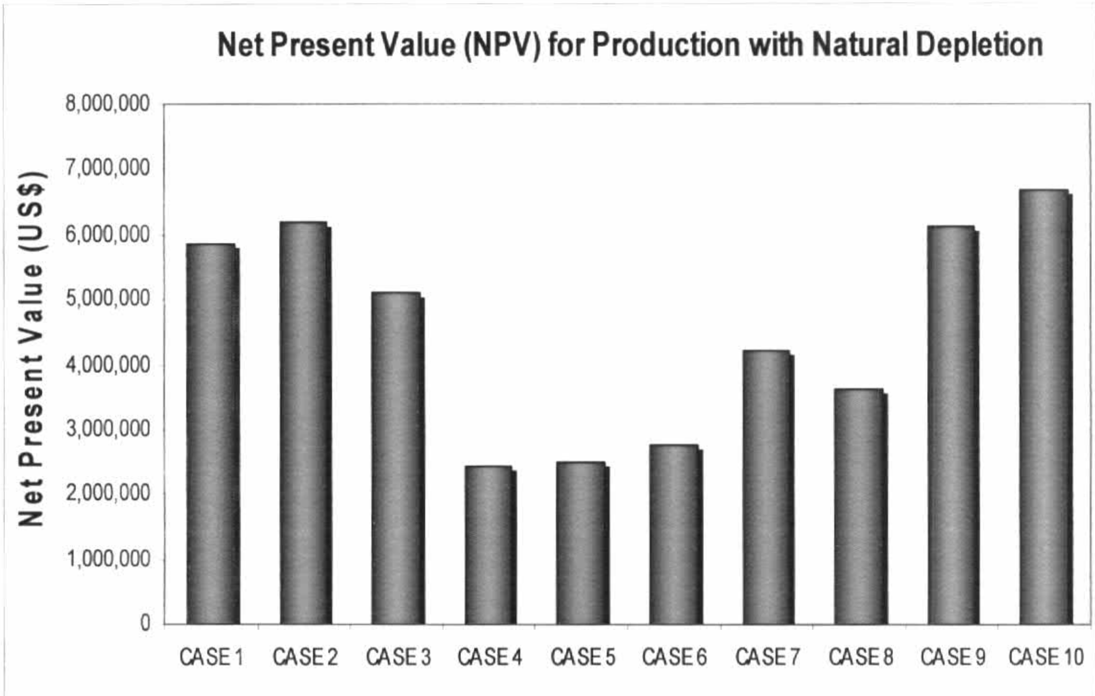


Figure 5.10: Net present values (NPV) with natural depletion.

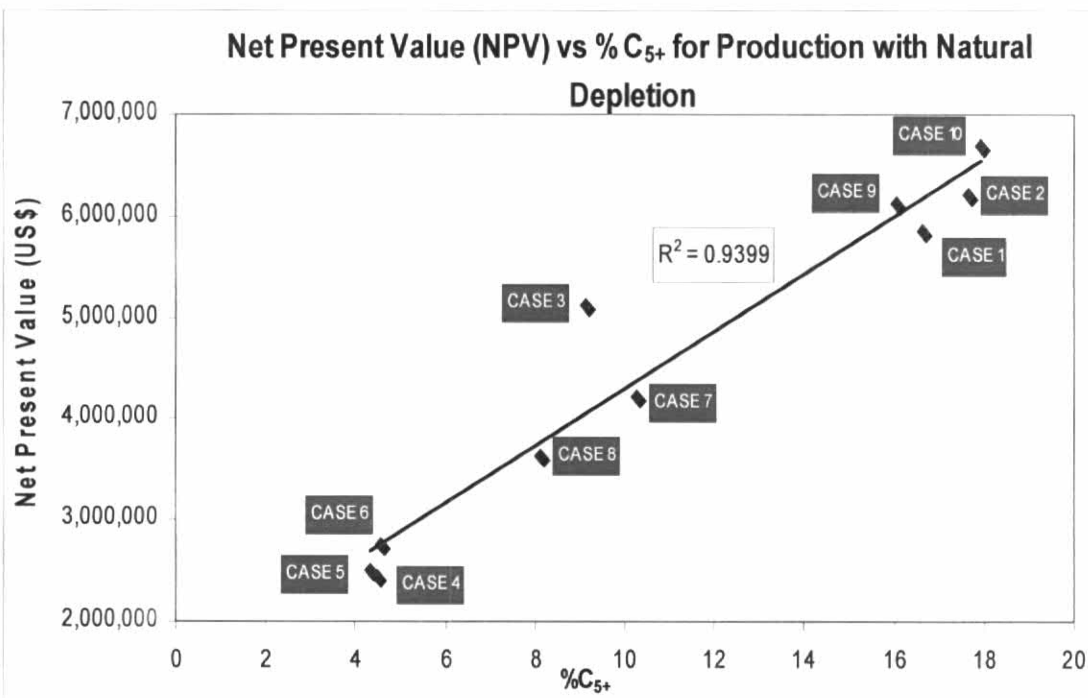


Figure 5.11: Net present values (NPV) for natural depletion as a function of mole percentage of C_{5+}.

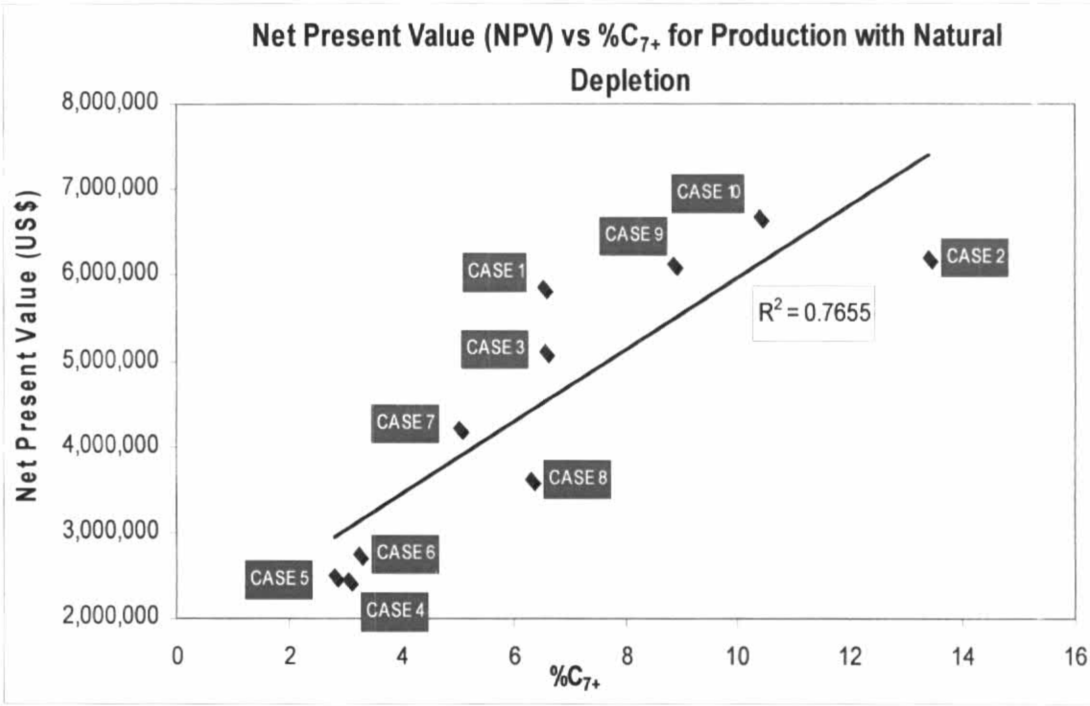


Figure 5.12: Net present values (NPV) for natural depletion as a function of mole percentage of C_{7+}.

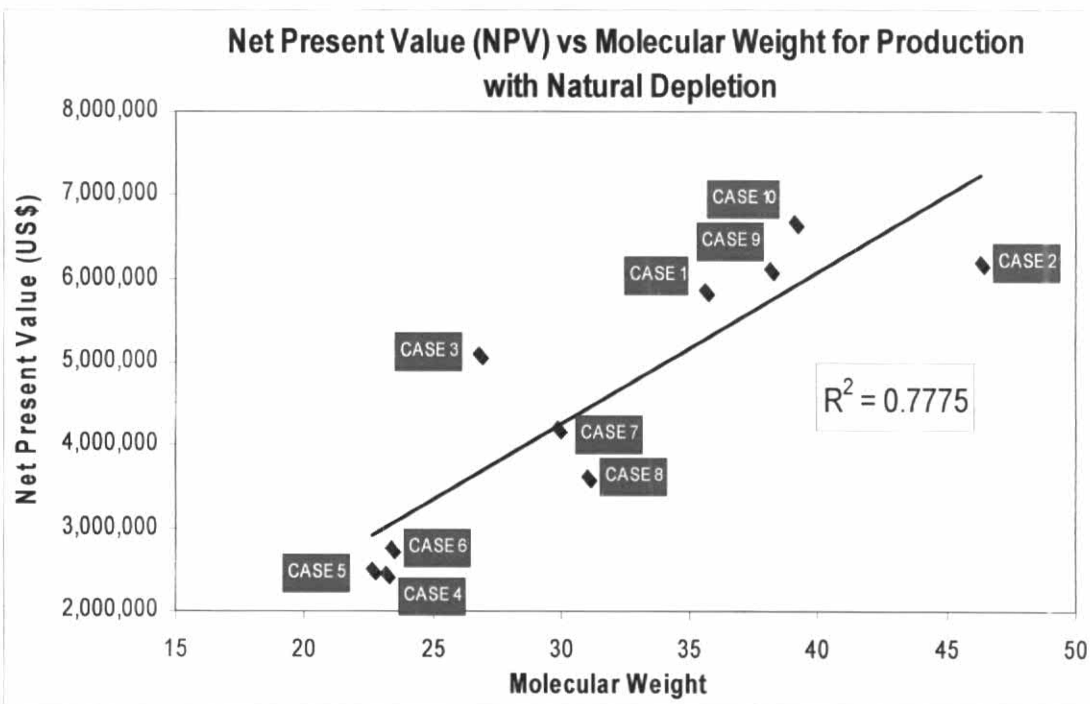


Figure 5.13: Net present values (NPV) for natural depletion as a function of molecular weight of the composition.

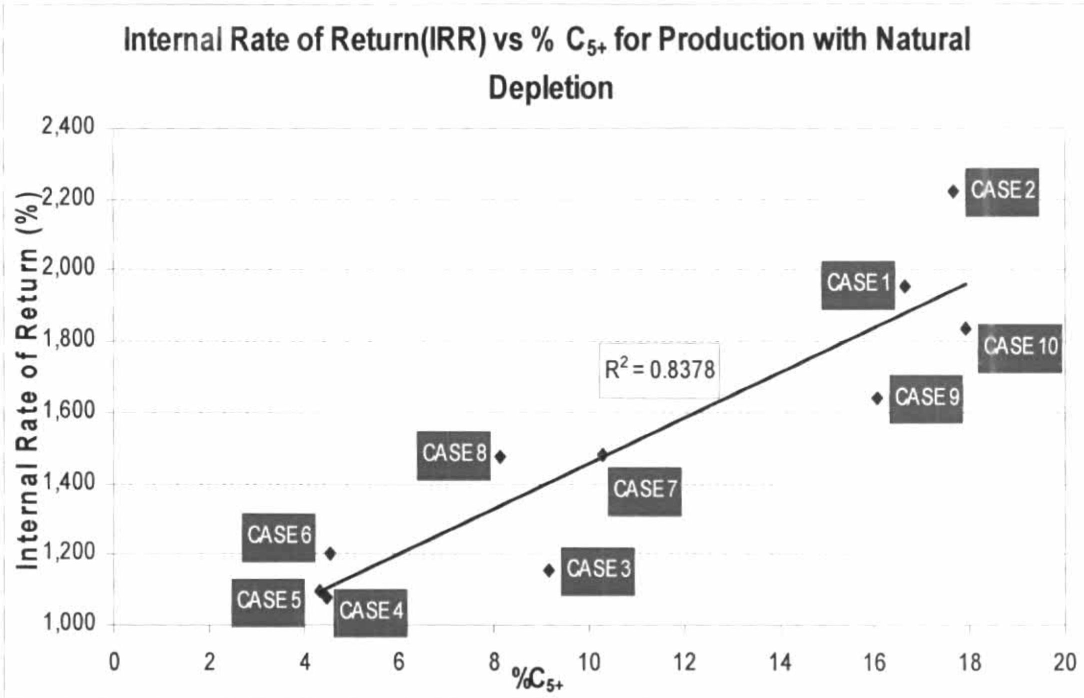


Figure 5.14: Internal rate of return (IRR) for production with natural depletion as a function of mole percentage of C_{5+}.

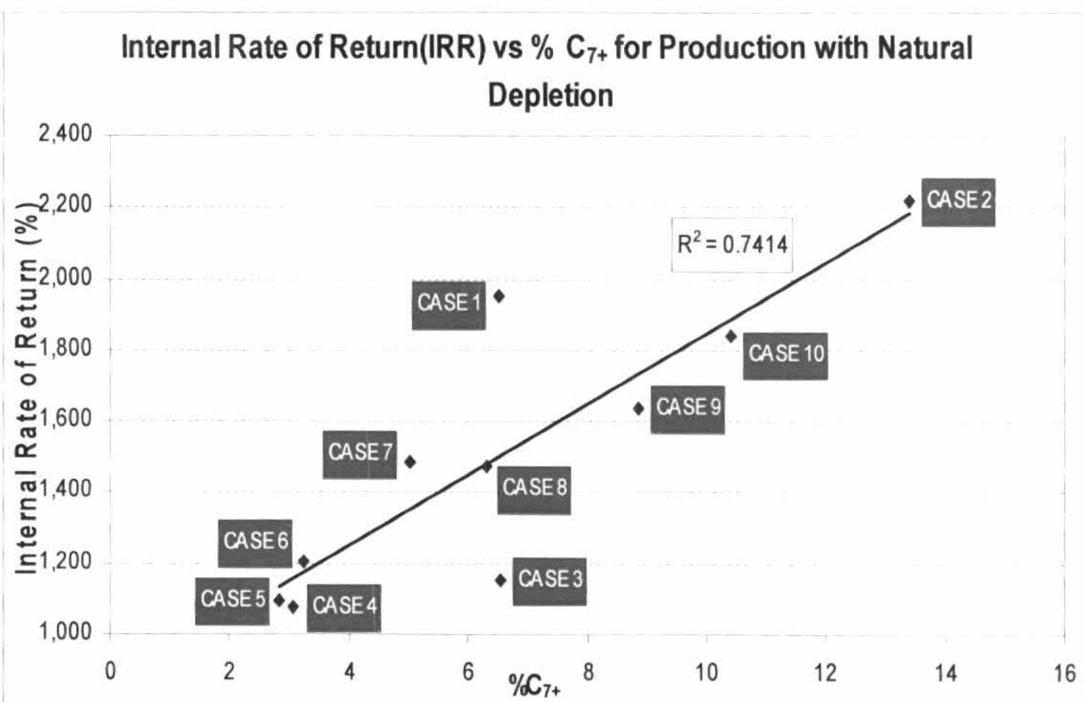


Figure 5.15: Internal rate of return (IRR) for production with natural depletion as a function of mole percentage of C_{7+}.

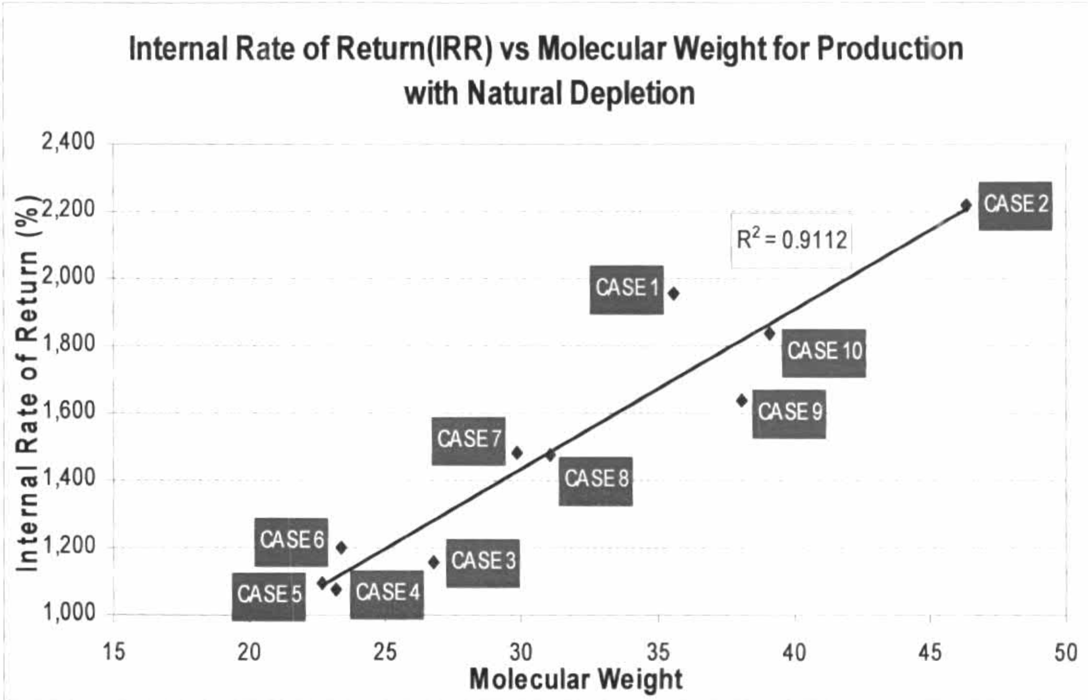


Figure 5.16: Internal rate of return (IRR) for production with natural depletion as a function of molecular weight of the composition.

5.3 Production of Gas-Condensate Reservoirs with Gas Cycling

Gas-Condensate reservoirs in this set of simulations are produced with gas cycling to maintain the reservoir pressure above the dew point pressure. In this method, produced gas is injected at the beginning of production with the same as the rate of production (5,000 MSCF/D). The production well is set on block (1,1), and the injection well is set on block (35,35) to simulate a quarter five-spot pattern. The produced gas is injected into the reservoirs until the production reaches the economic limits (oil rate = 5 STB/D): then, gas injection is stopped. After that, the production well continues to produce gas, and the injection well is switched to production until abandonment. Figure 5.17 shows the gas production rate obtained by running from simulation for ten sets of composition. The flat line for each case represents the gas rate produced from the producer. This gas is recycled by injecting back into the reservoirs. Figure 5.18 shows the oil production rate as function of time. Figure 5.19 show the total gas production where the straight line represents the total produced gas during the gas cycling period before switching the injection well to production well. Figure 5.20 shows the total oil production. The total gas and oil production are summarized in Table 5.3. Figures 5.21 and 5.22 depict the total gas and oil production for the ten sets of component, respectively.

Performance of gas-condensate reservoirs with gas cycling can be summarized as follows:

a) The total oil production (OPT) is in the range of 36,422 to 179,832 STB, and the total gas production (GPT) is in the range of 557 to 604 MMSCF. The total oil production and total gas production tend to depend on the mole percentage of C_{5+} and C_{7+} and molecular weight of the composition. The higher these values are, the higher the total production of gas and oil as shown in Figures 5.23 to 5.25.

b) The oil production rate limit is reached while the reservoir pressure is maintained nearly at the initial pressure. Thus, the remaining gas in the reservoirs contains little fractions of heavy-end hydrocarbons. The gas production after the injection is stopped has a slight change in composition.

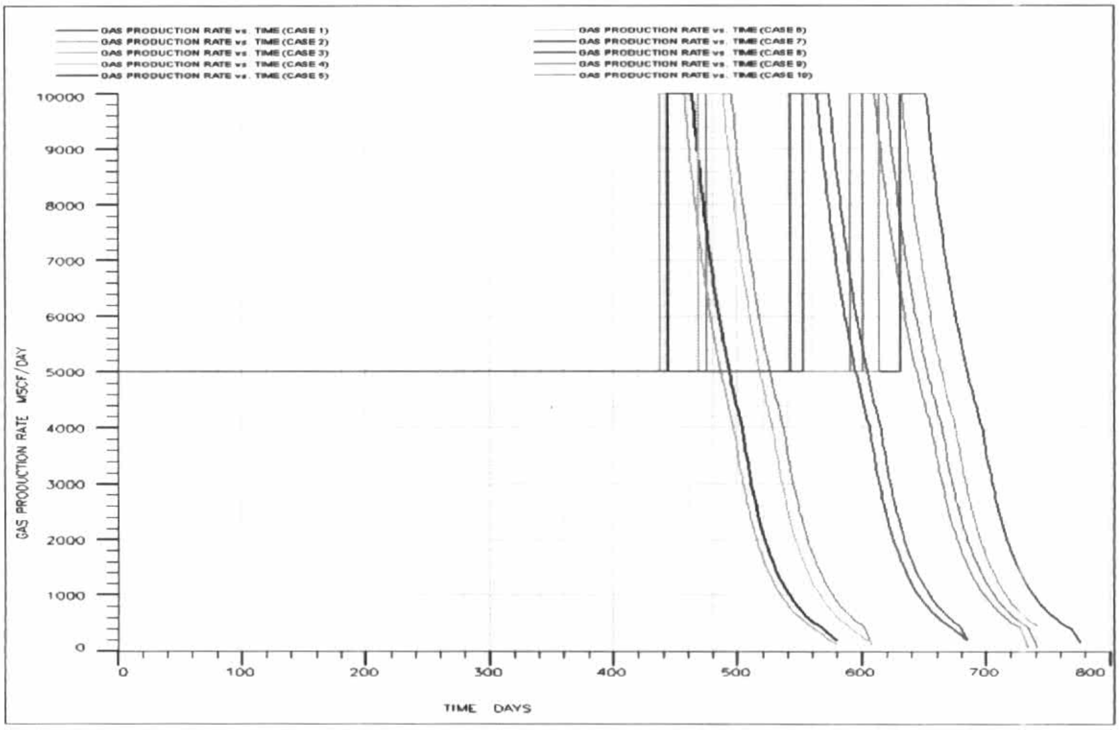


Figure 5.17: Gas production rates (GPR) for production with gas cycling.

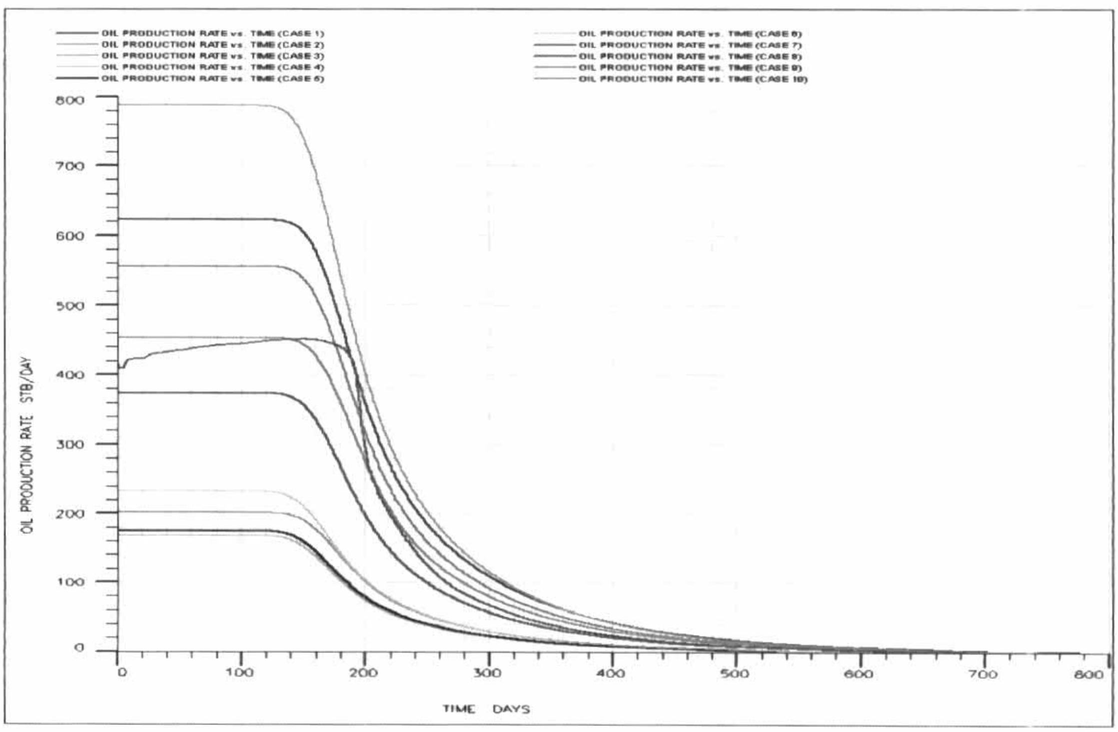


Figure 5.18: Oil production rates (OPR) for production with gas cycling.

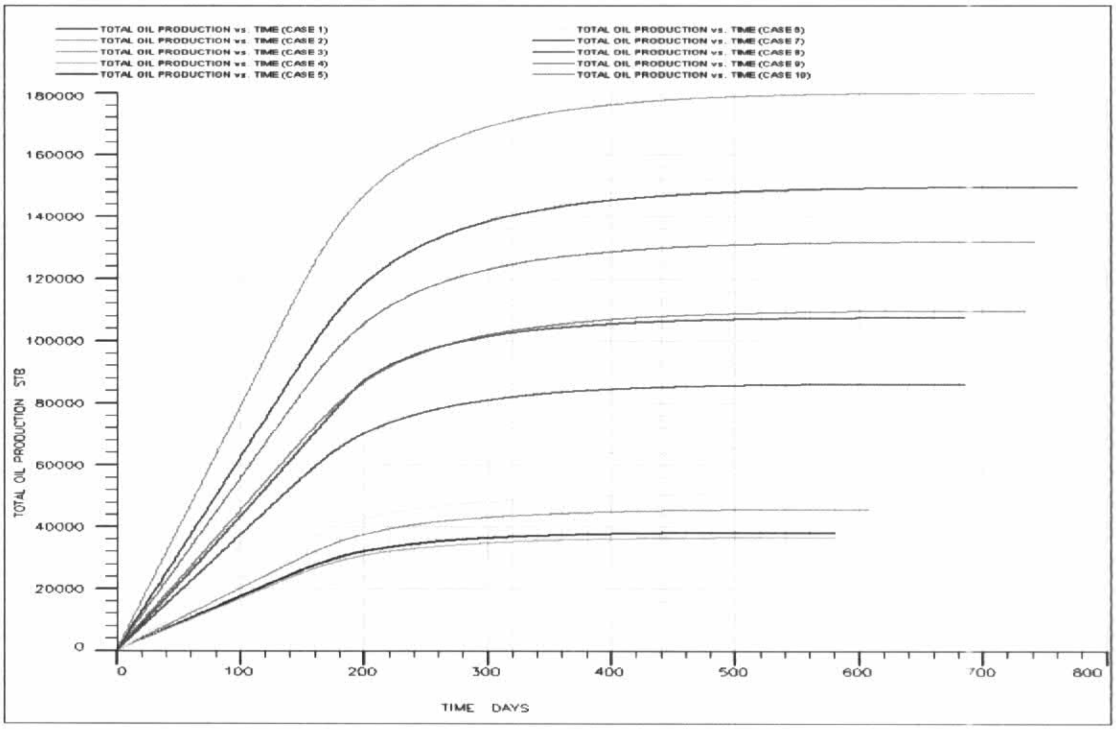


Figure 5.19: Total gas production (GPT) with gas cycling.

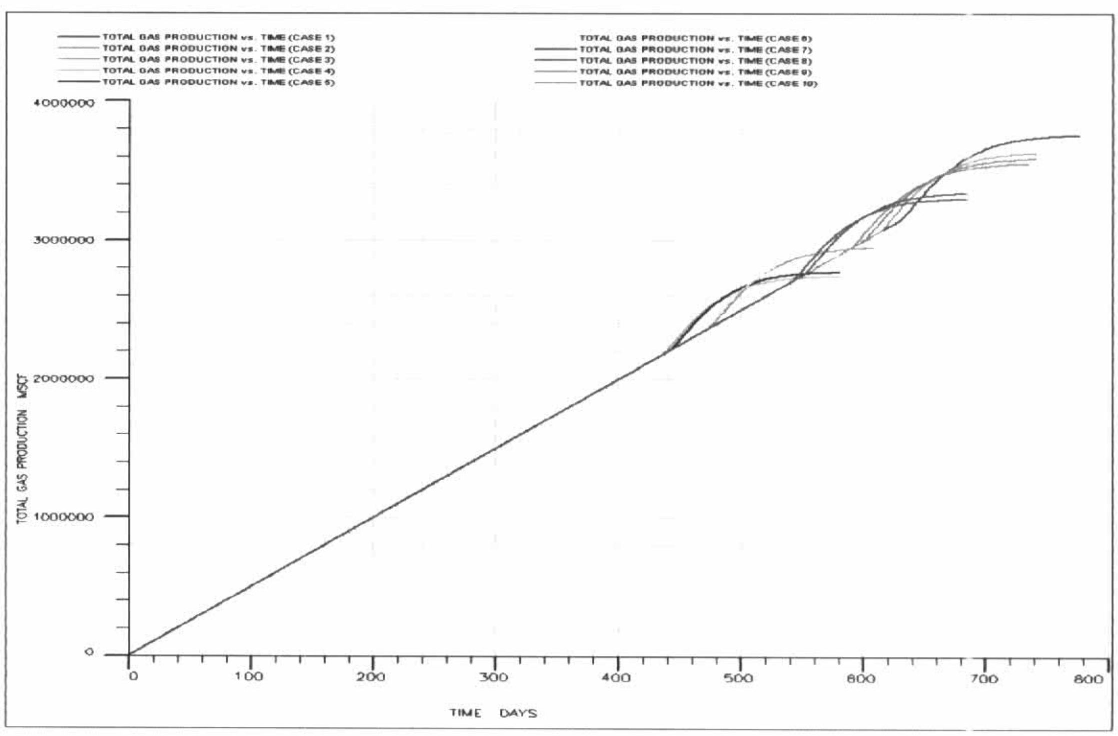


Figure 5.20: Total oil production (OPT) with gas cycling.

Table 5.3: Mole percentage of C_{5+} and C_{7+} and molecular weight, total gas production (GPT) and total oil production (OPT) with gas cycling.

#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular Weight	Total Gas production (MMSCF)	Total Oil production (STB)
1	16.64	6.54	35.60	604	149,487
2	17.66	13.39	46.33	565	179,832
3	9.15	6.56	26.80	587	45,622
4	4.50	3.06	23.19	559	38,160
5	4.35	2.83	22.65	558	36,422
6	4.56	3.26	23.41	557	50,594
7	10.28	5.03	29.87	591	86,162
8	8.14	6.33	31.04	580	107,339
9	16.07	8.85	38.12	598	109,592
10	17.92	10.4	39.10	590	131,794

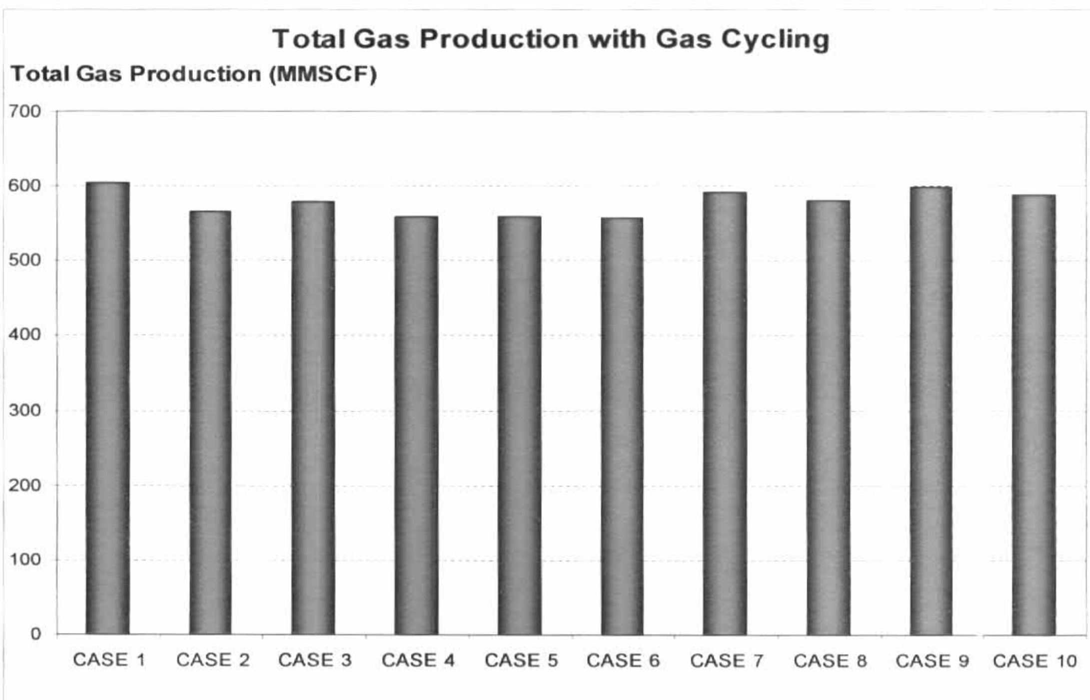


Figure 5.21: Total gas production (GPT) with gas cycling.

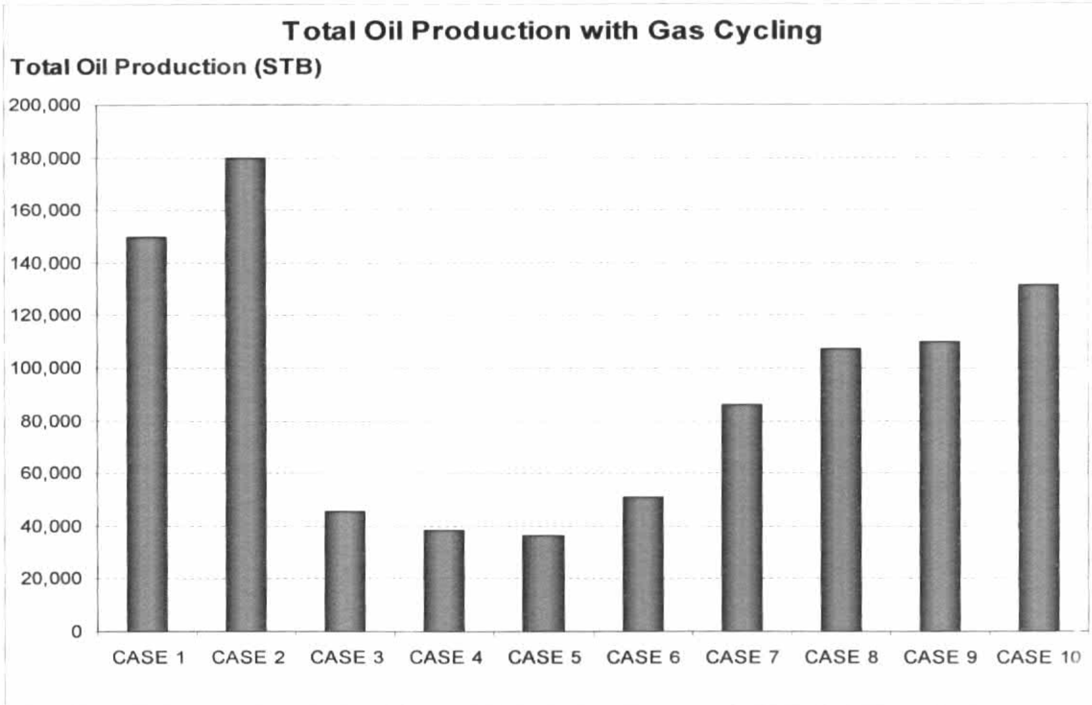
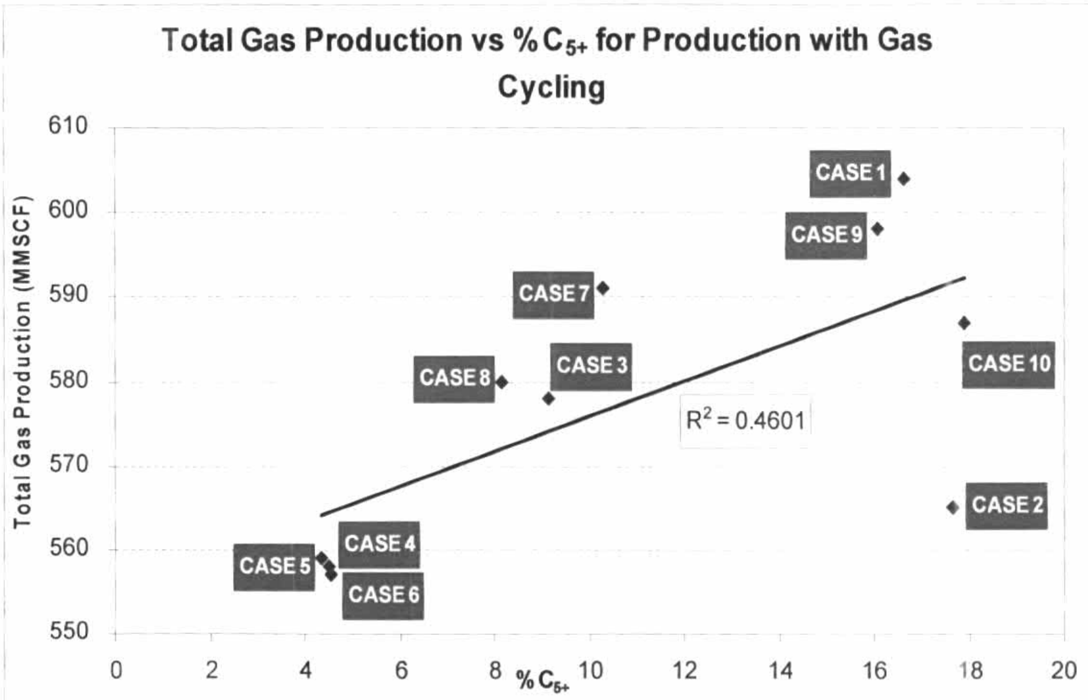
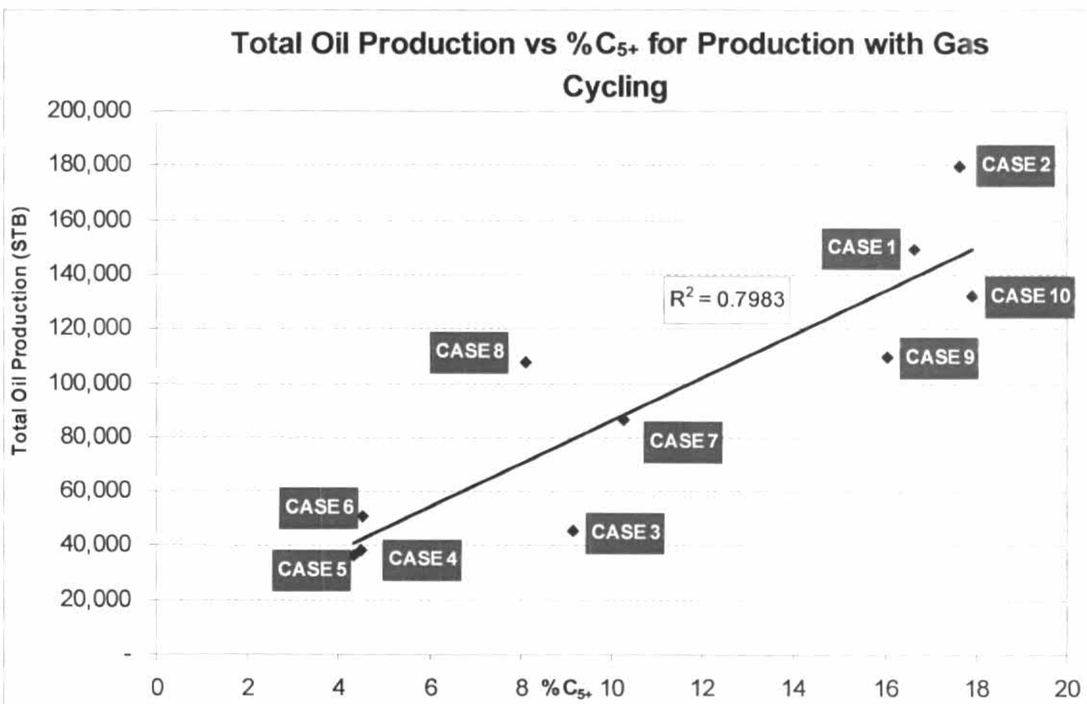


Figure 5.22: Total oil production (OPT) for production with gas cycling.

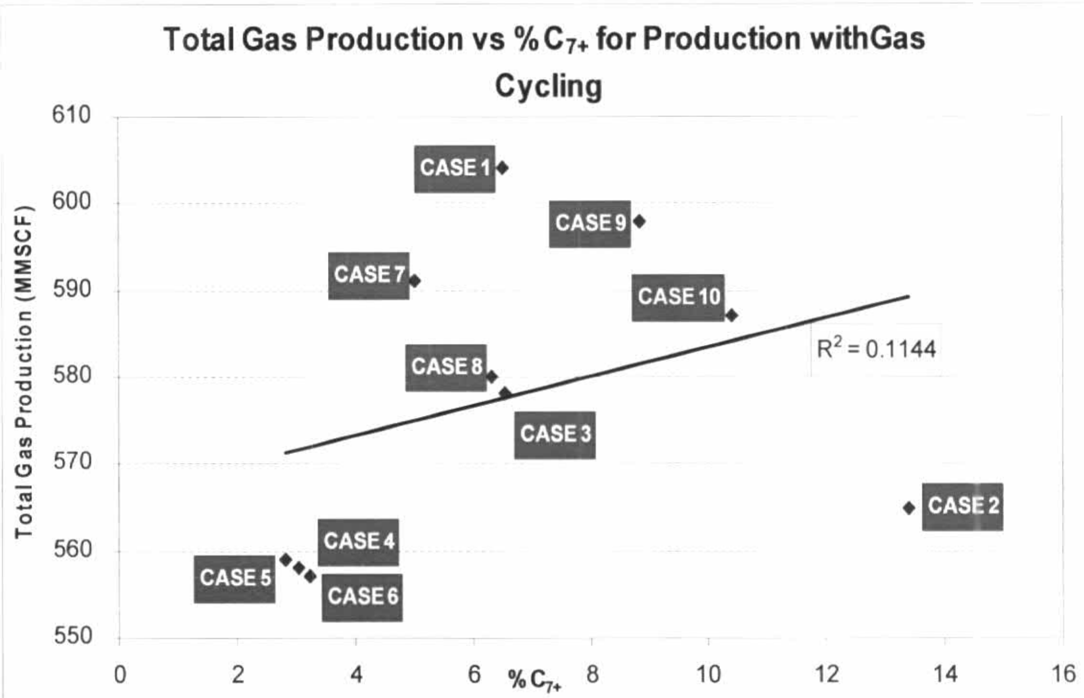


(a) Total gas production (GPT) with gas cycling as a function of mole percentage of C_{5+}.

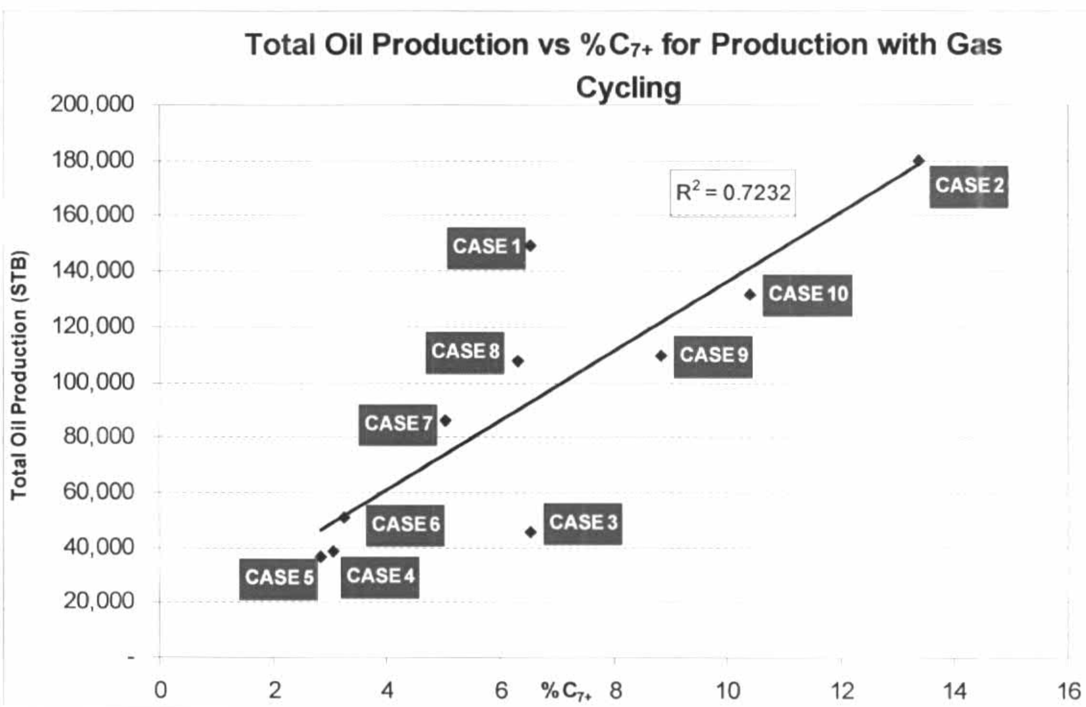


(b) Total oil production (OPT) with gas cycling as a function of mole percentage of C_{5+}.

Figure 5.23: Total gas and oil production for production with gas cycling as a function of mole percentage of C_{5+}.

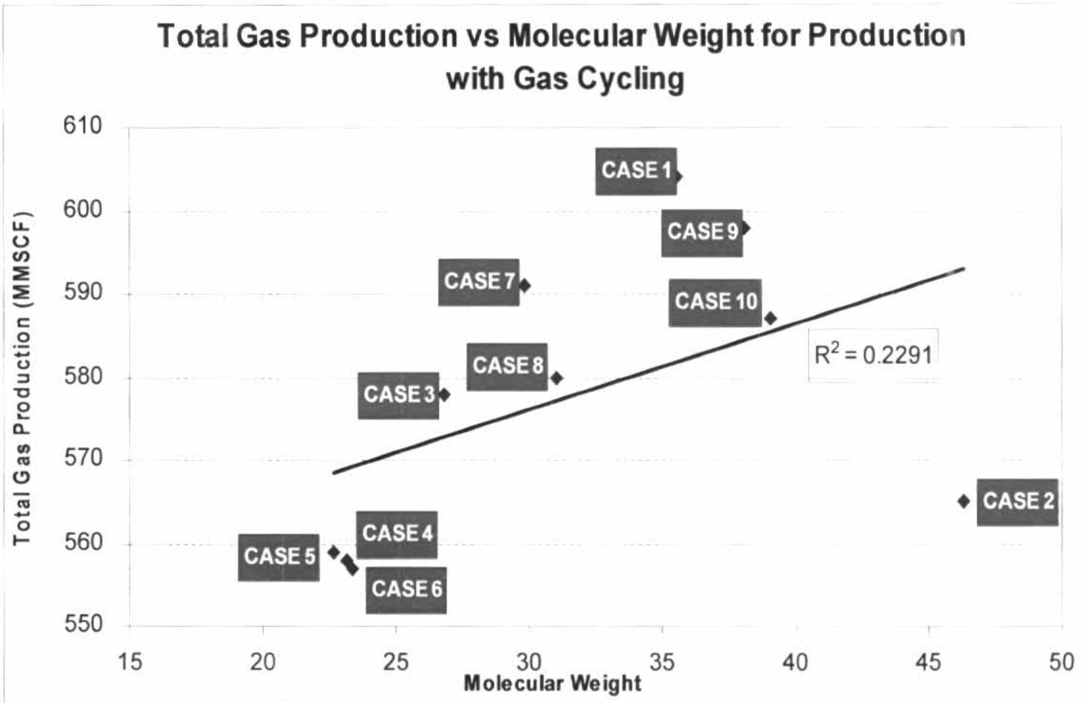


(a) Total gas production (GPT) with gas cycling as a function of mole percentage of C_{7+}.

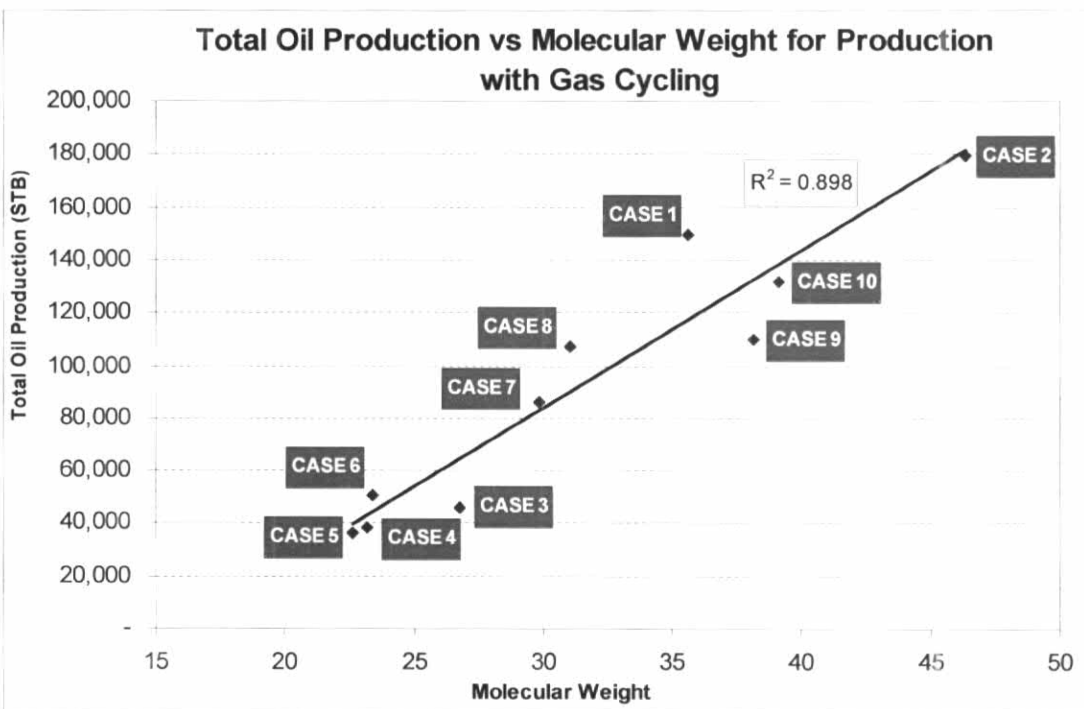


(b) Total oil production (OPT) with gas cycling as a function of mole percentage of C_{7+}.

Figure 5.24: Total gas and oil production for production with gas cycling as a function of mole percentage of C_{7+}.



(a) Total gas production (GPT) with gas cycling as function of molecular weight of the composition.



(b) Total oil production (OPT) for with gas cycling as a function of molecular weight of the composition.

Figure 5.25: Total gas and oil production for production with gas cycling as a function of percentage of molecular weight of the composition.

5.4 Economic Analysis for Production of Gas-Condensate Reservoirs with Gas Cycling

Economic analysis for production with gas cycling is summarized in Table 5.4 and NPV of each case is graphically illustrated in Figure 5.26. All production profiles give positive net present values and higher internal rate of return than the discount rate (10%) used in this study. All production rates with gas cycling are financially acceptable for investment.

The economic analysis for production of gas-condensate reservoirs with gas cycling can be summarized as follows:

a) All the cases are economically acceptable for project investment. Each NPV is more than zero, and the IRR is higher than the discount rate of 10 %.

b) For the payback period, it can be concluded that the lower the mole percentage of C_{5+} and C_{7+} and molecular weight, the longer the payback period.

c) Since the ratio of producers to injector will change when the area of interest changes, the larger the area of interest, the lower the ratio will be as shown in Figure 5.27. In this study, the conservative estimation is computed by using the 1:1 ratio of production and injection well.

d) The total oil production (OPT) contributes to the net present value greater than the total gas production (GPT). The elevated recovery of cumulative oil production is a result of gas cycling process and results in a high net present value.

e) NPV tends to increase when the reservoir composition has more mole percentage of C_{5+}, C_{7+} or molecular weight as depicted in Figures 5.28 to 5.30.

f) One of the factors which can cause negative IRR is the well cost. Figure 5.31 shows the sensitivity of IRR as a function of well cost from 1.2 to 10 MMUSD. The IRR values for all production scenarios in this study are tabulated in Table 5.5. This sensitivity analysis shows that of the cost of the injection well is high, gas recycling may not be feasible.

Table 5.4: Net present value (NPV), internal rate of return (IRR) and payback period with gas cycling for each set of component.

#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular Weight	Net Present Value (NPV, US$)	Internal Rate of Return (IRR, %)	Payback Period (Days)
1	16.64	6.54	35.60	8,040,697	335	135
2	17.66	13.39	46.33	9,556,390	457	107
3	9.15	6.56	26.80	1,753,658	65	580
4	4.50	3.06	23.19	943,955	43	580
5	4.35	2.83	22.65	843,826	36	580
6	4.56	3.26	23.41	1,577,612	67	580
7	10.28	5.03	29.87	4,116,879	158	545
8	8.14	6.33	31.04	4,846,601	214	195
9	16.07	8.85	38.12	5,896,477	216	195
10	17.92	10.4	39.10	7,084,252	290	153

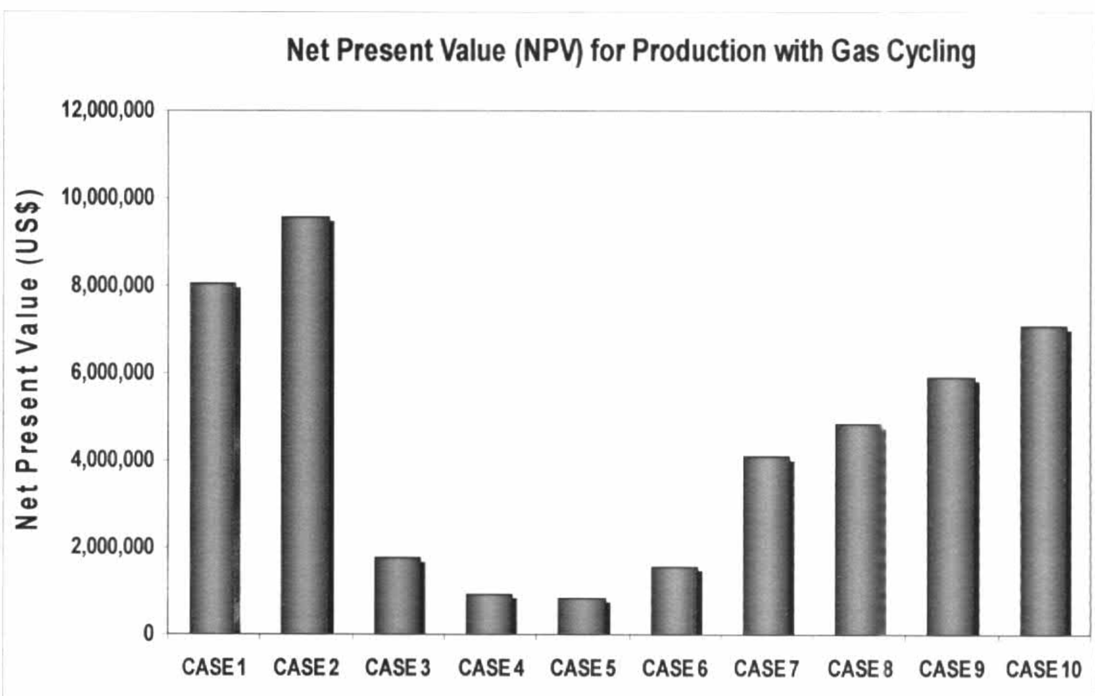
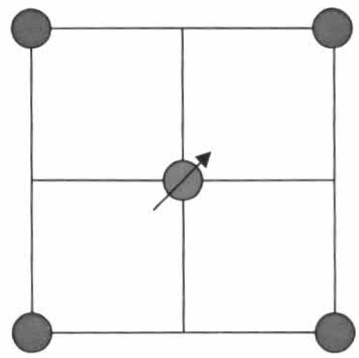
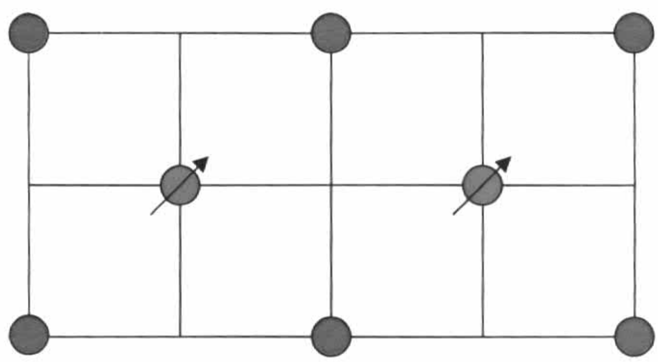


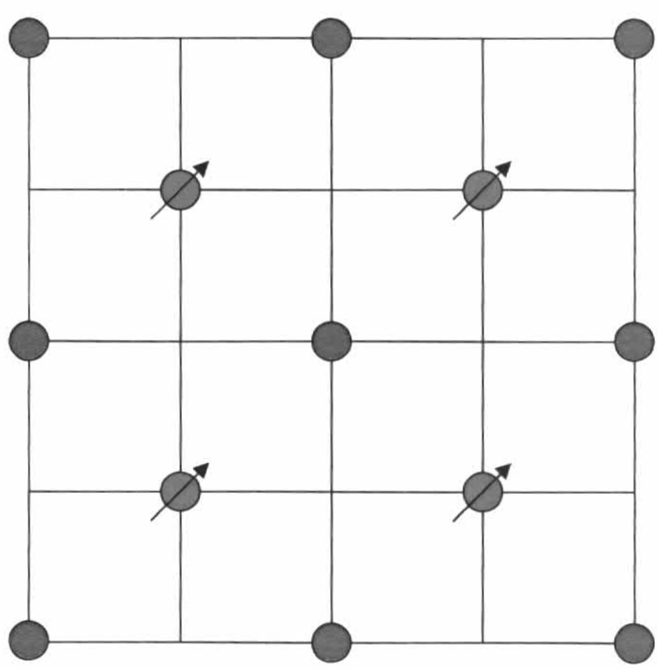
Figure 5.26: Net present value (NPV) for production with gas cycling each set of component.



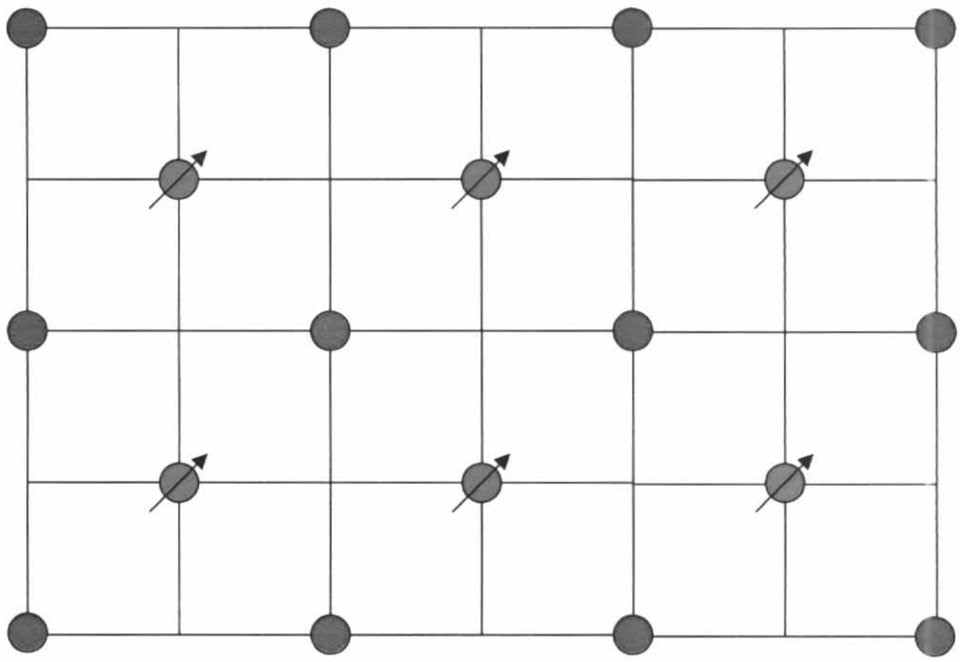
a) Five spot flooding pattern using the 4:1 ratio of production and injection well



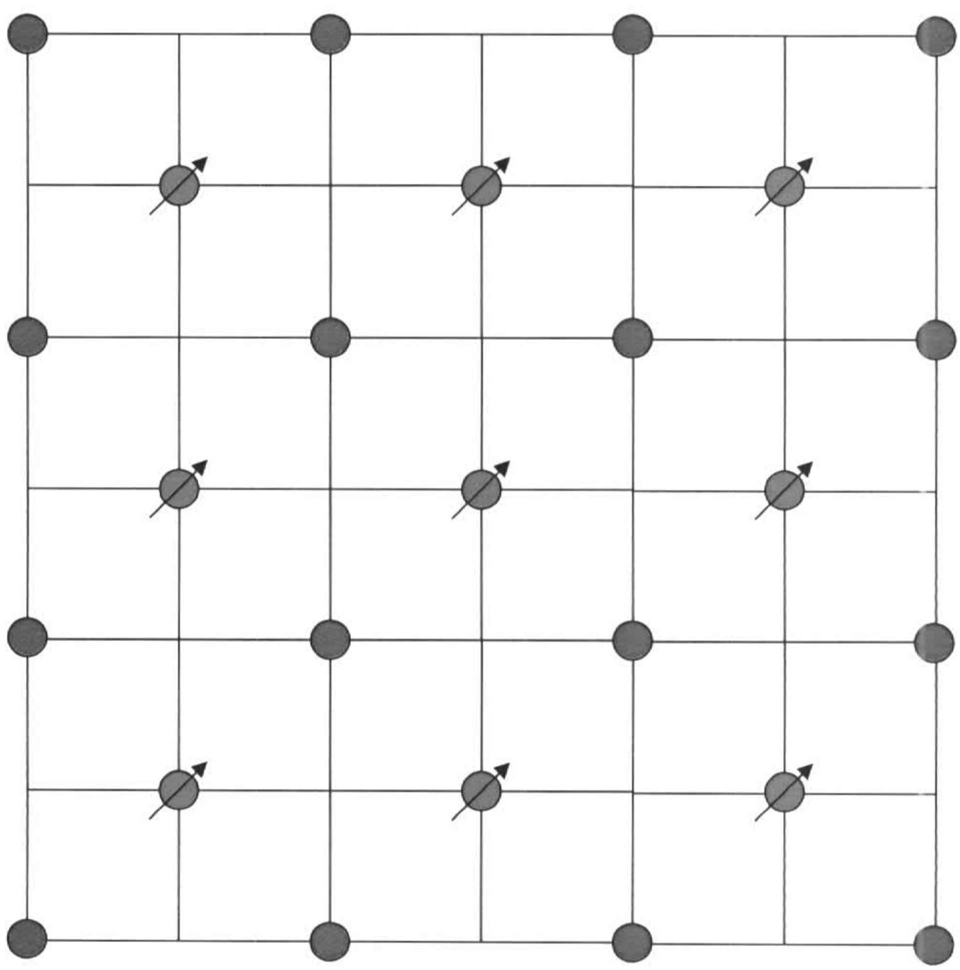
b) Five spot flooding pattern using the 3:1 ratio of production and injection well



c) Five spot flooding pattern using the 9:4 ratio of production and injection well



d) Five spot flooding pattern using the 2:1 ratio of production and injection well



e) Five spot flooding pattern using the 16:9 ratio of production and injection well

Figure 5.27: Examples of five spot flooding pattern of gas cycling.

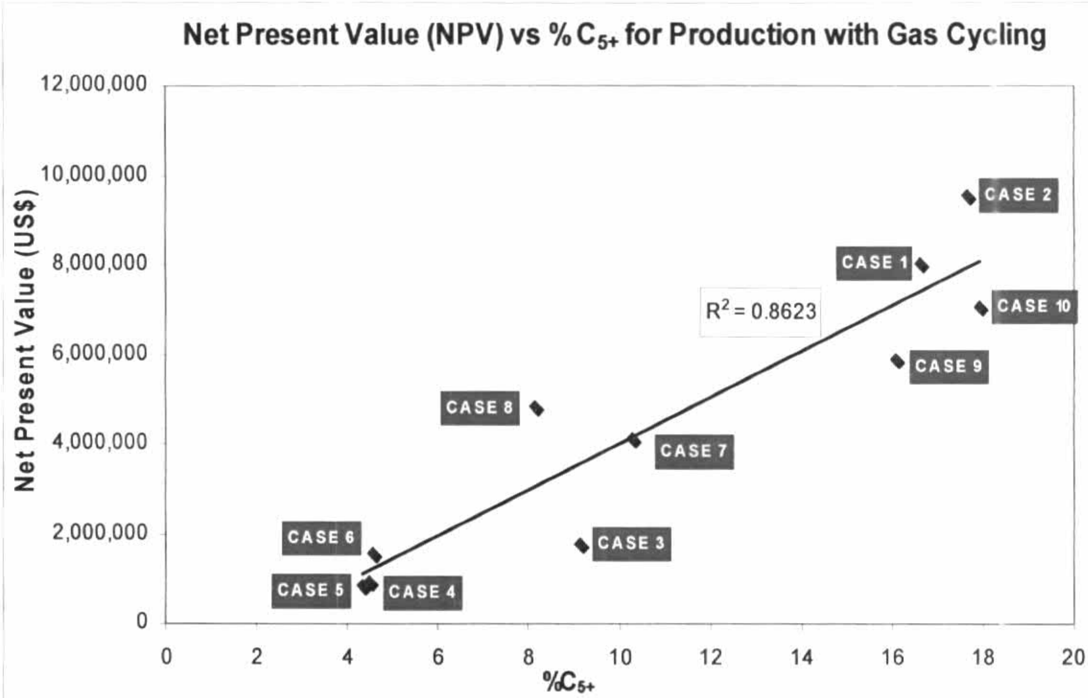


Figure 5.28: Net present value (NPV) for production with gas cycling as a function of mole percentage of C_{5+}.

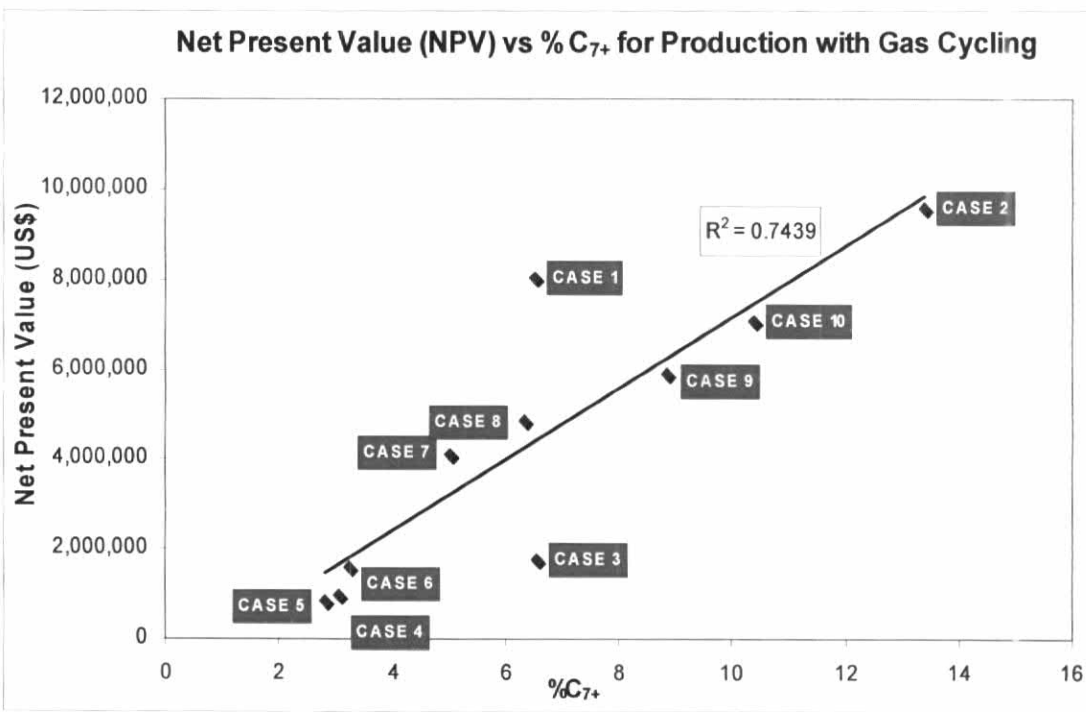


Figure 5.29: Net present value (NPV) for production with gas cycling as a function of mole percentage of C_{7+}.

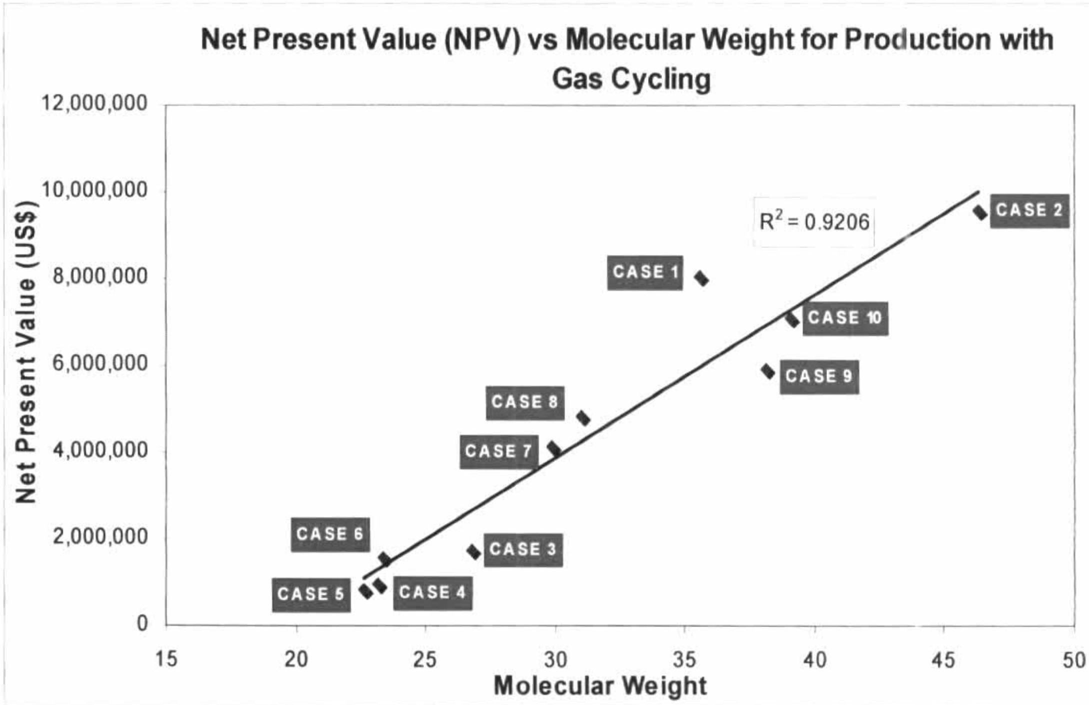


Figure 5.30: Net present value (NPV) for production with gas cycling as a function of molecular weight of the composition.

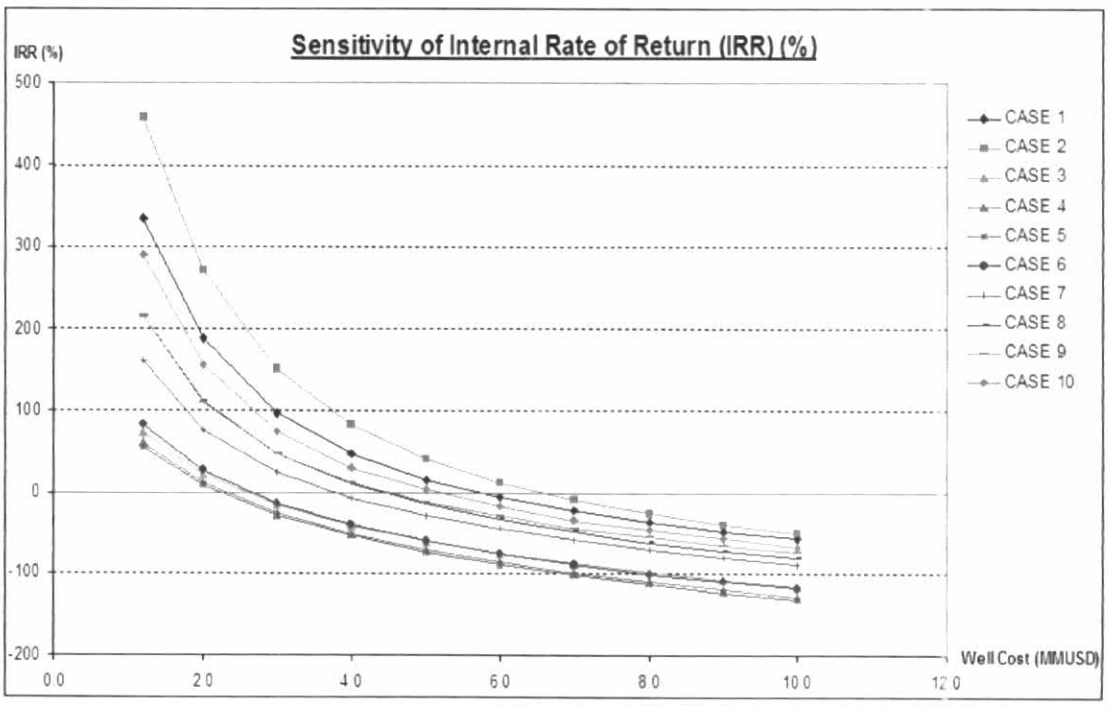


Figure 5.31: Sensitivity of internal rate of return and producer and injector well cost.

Table 5.5: Internal rate of return (IRR) for each set of component and each well cost.

Well Cost (MMUSD)	Internal Rate of Return (IRR, %) CASE 1	Internal Rate of Return (IRR, %) CASE 2	Internal Rate of Return (IRR, %) CASE 3	Internal Rate of Return (IRR, %) CASE 4	Internal Rate of Return (IRR, %) CASE 5	Internal Rate of Return (IRR, %) CASE 6	Internal Rate of Return (IRR, %) CASE 7	Internal Rate of Return (IRR, %) CASE 8	Internal Rate of Return (IRR, %) CASE 9	Internal Rate of Return (IRR, %) CASE 10
1.2	335	188	96	47	15	-7	-23	-37	-48	-57
2.0	457	272	150	81	39	9	-12	-29	-42	-54
3.0	65	14	-24	-49	-69	-84	-96	-107	-117	-125
4.0	43	-7	-45	-71	-91	-107	-120	-131	-141	-150
5.0	36	-12	-50	-75	-95	-110	-123	-135	-145	-153
6.0	67	9	-32	-59	-79	-95	-109	-120	-130	-139
7.0	158	72	20	-12	-34	-51	-65	-77	-86	-95
8.0	214	104	36	-3	-29	-49	-64	-77	-88	-97
9.0	216	111	49	14	-10	-27	-41	-53	-63	-71
10.0	290	156	75	32	4	-17	-33	-45	-56	-65

5.5 Natural Depletion and Production with Gas Cycling

Simulation results of production by natural depletion and production with gas cycling are compared to evaluate the production strategy for different hydrocarbon compositions.

5.5.1 BottomHole Pressure (BHP)

As mentioned before, the main objective of gas injection or gas cycling is to maintain the gas-condensate reservoir pressure above the dew point. In order to confirm the effect of gas injection on pressure, the bottomhole pressure (BHP) of the production well in the case of natural depletion and gas cycling scenario obtained from the simulations are shown in Figures 5.32 to 5.33, respectively.

The bottomhole pressure of the production well in the case of natural depletion steeply declines from the initial reservoir pressure to a value around 1,480 psia when the economic production rate of gas has already reached. The bottomhole pressure is reduced to sustain that constant gas rate. However, when the reservoirs cannot produce gas at the fixed rate, the control is switched to the bottomhole pressure rather than constant rate. Thus, the gas continues to produce till the production well is shut-in at abandonment.

In case of production with gas cycling, the bottomhole pressure of the production well is stable flat and maintained approximately at the initial pressure as shown in Figure 5.34. This constant pressure results from the gas cycling process. The bottomhole pressure is constant until the well oil production rate reaches the minimum oil production rate or economic limit (5 STB/D). At this condition, the gas cycling process is stopped and the injection well is switched to production. Consequently, the bottomhole pressure immediately drops to about 1,480 psia as depicted in Figure 5.35.

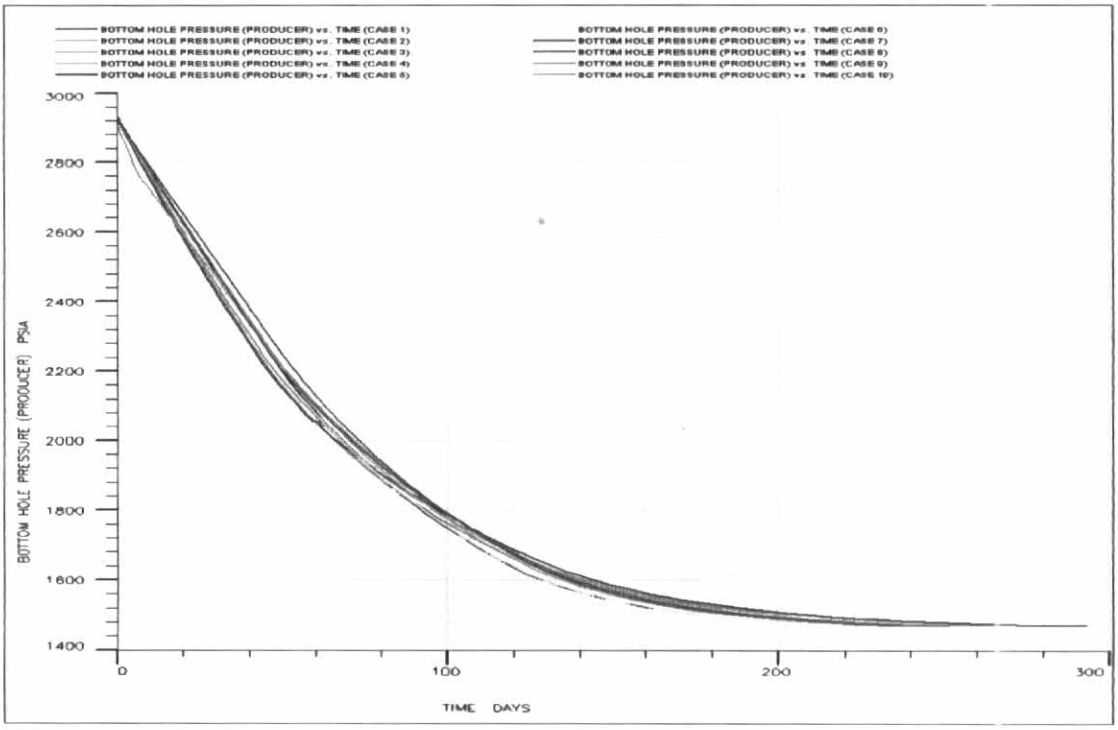


Figure 5.32: Bottomhole pressure (BHP) of production well for production with natural depletion.

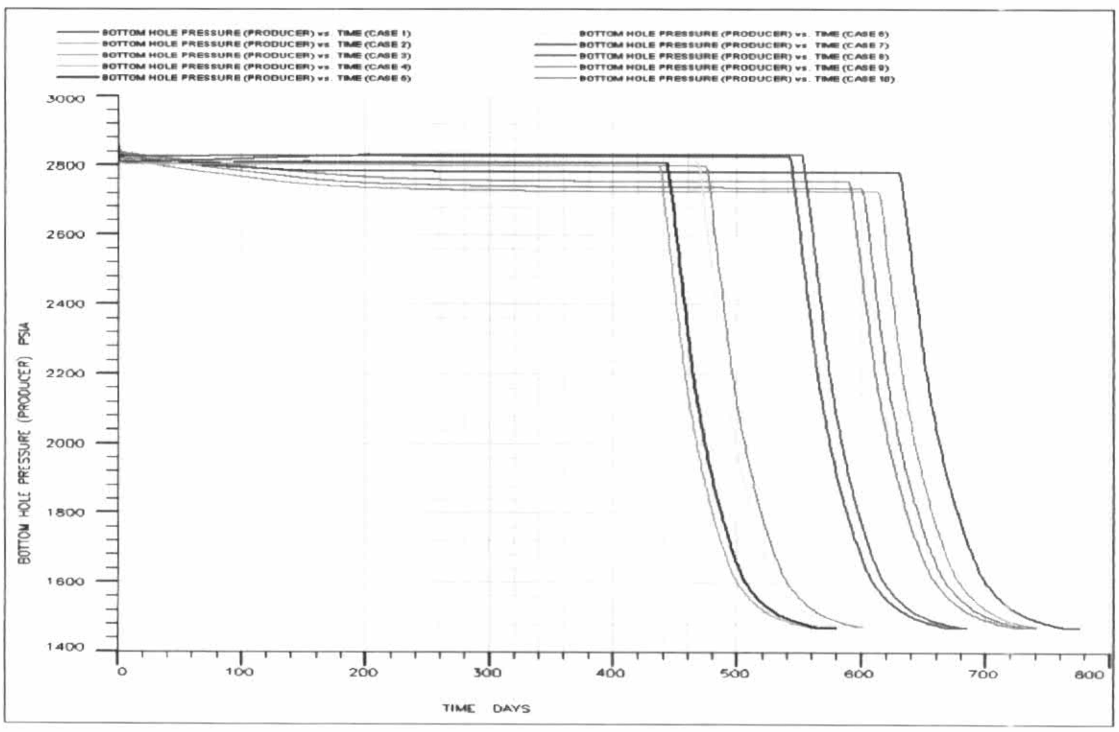


Figure 5.33: Bottomhole pressure (BHP) of production well for production with gas cycling.

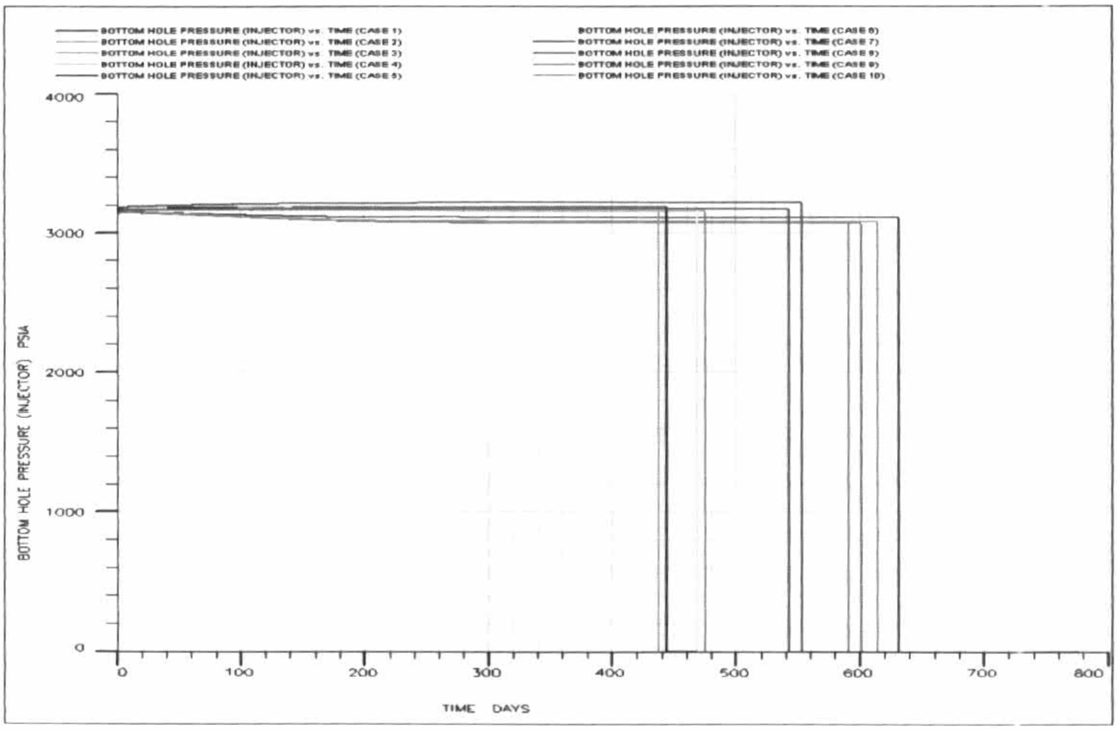


Figure 5.34: Bottomhole pressure (BHP) of injection well for production with gas cycling.

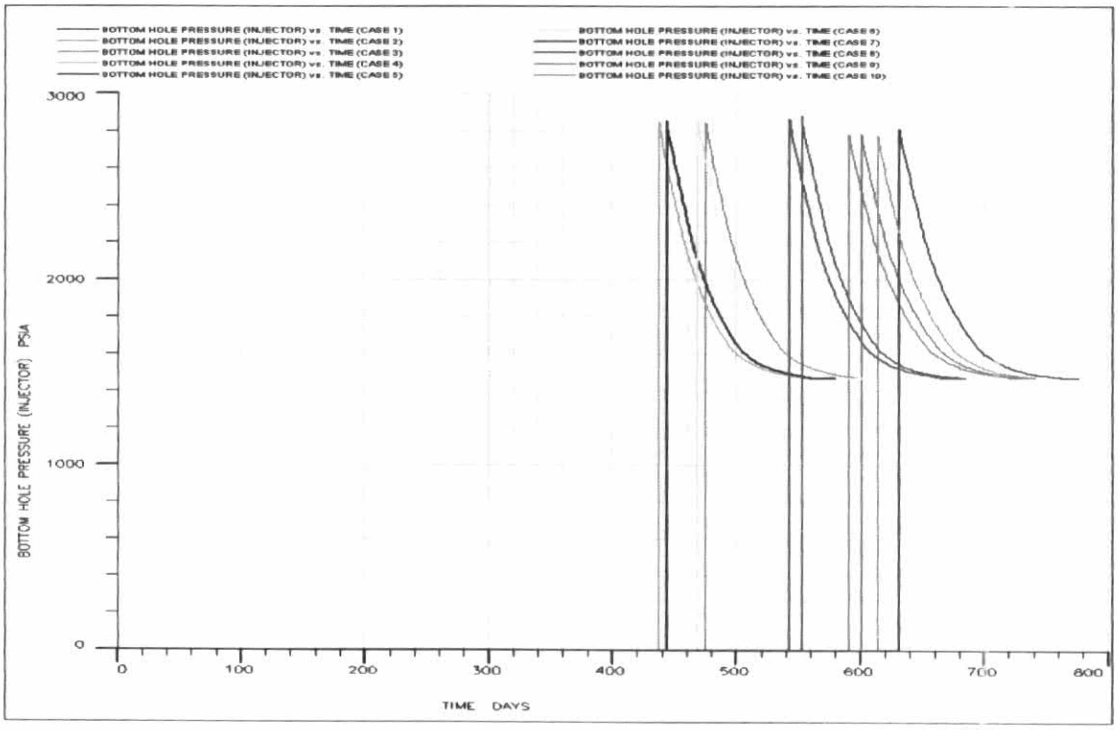


Figure 5.35: Bottomhole pressure (BHP) of injection well for production with gas cycling after being switched to production.

5.5.2 Total Gas Production

From the results of the simulations, the total gas production (GPT) in the case of nature depletion is almost the same as the total gas production with gas cycling. Table 5.6 summarizes results of total gas production from production with natural depletion and gas cycling for the ten sets of composition. Figure 5.36 shows a comparison of the total gas production (GPT) between the two recovery mechanisms. The total gas production from production with gas cycling is around 0.17% - 3.91% different with natural depletion.

Table 5.6: Total gas production (FGPT) with natural depletion and gas cycling.

#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular Weight	Gas Production Total : Production by Natural Depletion (MMSCF)	Gas Production Total : Production with Gas Cycling (MMSCF)	Percentage of Gas Change (%)
1	16.64	6.54	35.60	595	604	**1.51**
2	17.66	13.39	46.33	588	565	**-3.91**
3	9.15	6.56	26.80	579	578	**-0.17**
4	4.50	3.06	23.19	555	558	**0.54**
5	4.35	2.83	22.65	557	559	**0.36**
6	4.56	3.26	23.41	558	557	**-0.18**
7	10.28	5.03	29.87	589	591	**0.34**
8	8.14	6.33	31.04	589	580	**-1.53**
9	16.07	8.85	38.12	590	598	**1.36**
10	17.92	10.4	39.10	577	587	**1.73**

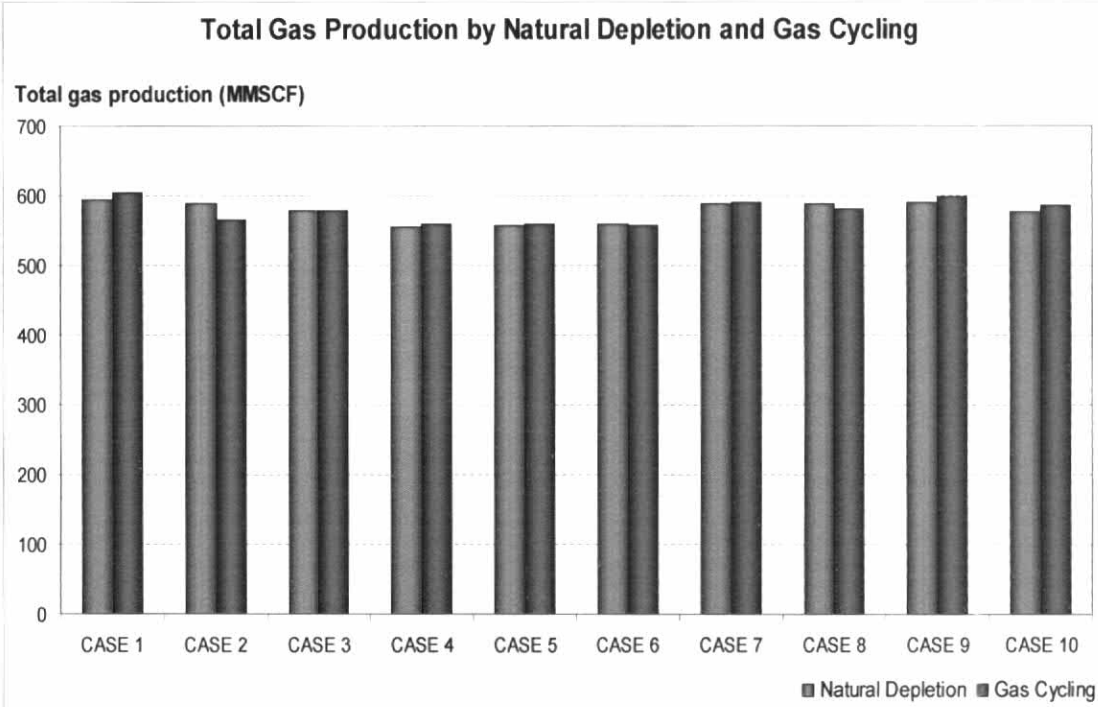


Figure 5.36: Total gas production (GPT) for production with natural depletion and gas cycling.

5.5.3 Total Oil Production

The total oil production (OPT) for both scenarios of production is tabulated in Table 5.7. Figure 5.37 depicts the numbers in a graphical form. The total oil production from production with gas cycling is about 89-247% higher than the total oil production by natural depletion. The total oil production tends to increase respect to the increasing of the mole percentage of C_{5+} or C_{7+} and molecular weight of the composition when the value of root mean square is considered.

Table 5.7: Total oil production (OPT) of production with natural depletion and gas cycling.

#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular Weight	Natural Depletion : Oil production total (STB)	Gas Cycling : Oil production total (STB)	Percentage of Oil Increasing (%)
1	16.64	6.54	35.60	61,126	149,487	**144.56**
2	17.66	13.39	46.33	54,519	179,832	**229.85**
3	9.15	6.56	26.80	23,313	45,622	**95.69**
4	4.50	3.06	23.19	18,661	38,160	**104.49**
5	4.35	2.83	22.65	19,307	36,422	**88.65**
6	4.56	3.26	23.41	22,937	50,594	**120.58**
7	10.28	5.03	29.87	36,510	86,162	**136.00**
8	8.14	6.33	31.04	30,976	107,339	**246.52**
9	16.07	8.85	38.12	53,429	109,592	**105.12**
10	17.92	10.4	39.10	63,306	131,794	**108.19**

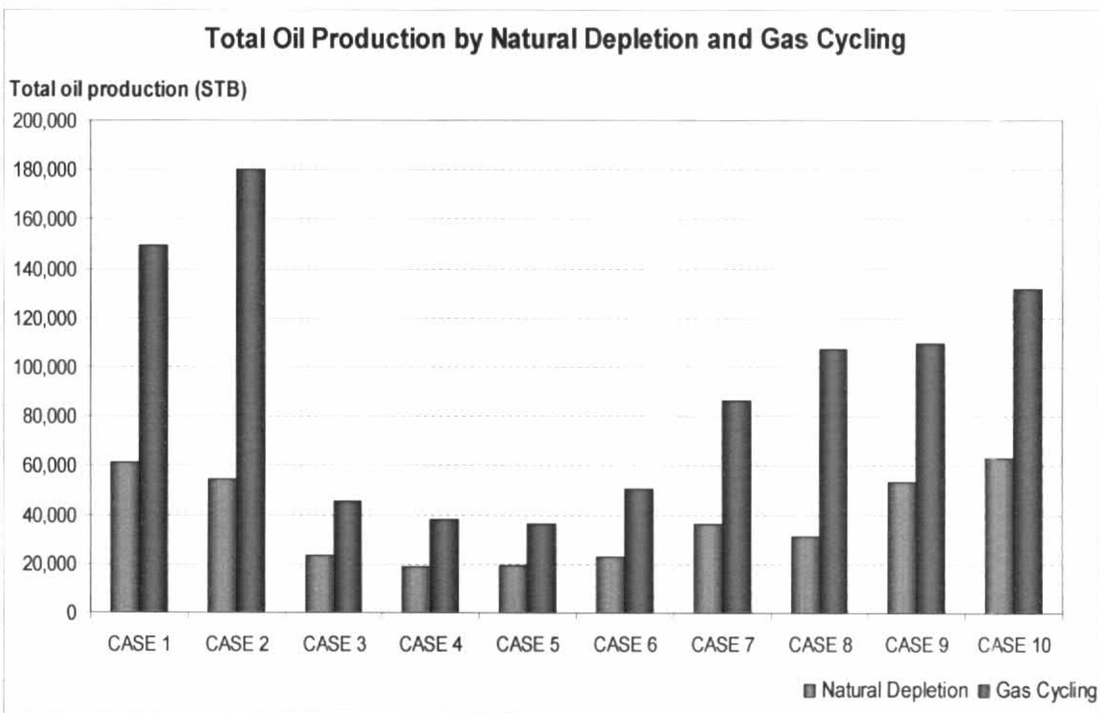


Figure 5.37: Total oil production (OPT) for production with natural depletion and gas cycling.

5.5.4 Economic Comparison for Production Profiles

In summary, the simulation results for all production scenarios are analyzed in term of economics. As discussed at the end of Chapter IV, net present value (NPV) is one of the economic parameters that can be used as a criterion for the optimum production profile of gas-condensate reservoirs. The net present values for both production scenarios for the ten compositions used in this study are tabulated in Table 5.8. For this particular sets of gas-condensate reservoirs, production with gas cycling remunerates higher net present values in cases 1, 2, 8, and 10. The other six cases have lower NPV when gas cycling is implemented. Figures 5.38 to 5.41 show the NPV gain as a function of the mole percentage of C_{5+} and C_{7+} and molecular weight of the composition when gas cycling is implemented. This fact illustrates that each project should be evaluated with great care before a decision is made. From the economic analysis, only the sets of hydrocarbon component which has molecular weight greater than 30 give better NPV when gas cycling is implemented.

Table 5.8: Net present value (NPV) for all studied scenarios.

Net Present Value (NPV, US$)					
#No. Composition	C_{5+} (%)	C_{7+} (%)	Molecular weight	Production Profiles	
				Natural Depletion	Gas Cycling
1	16.64	6.54	35.60	5,859,539	8,040,697
2	17.66	13.39	46.33	6,200,802	9,556,390
3	9.15	6.56	26.80	5,107,988	1,753,658
4	4.50	3.06	23.19	2,445,064	943,955
5	4.35	2.83	22.65	2,509,754	843,826
6	4.56	3.26	23.41	2,753,895	1,577,612
7	10.28	5.03	29.87	4,223,341	4,116,879
8	8.14	6.33	31.04	3,625,051	4,846,601
9	16.07	8.85	38.12	6,127,300	5,896,477
10	17.92	10.40	39.10	6,688,813	7,084,252

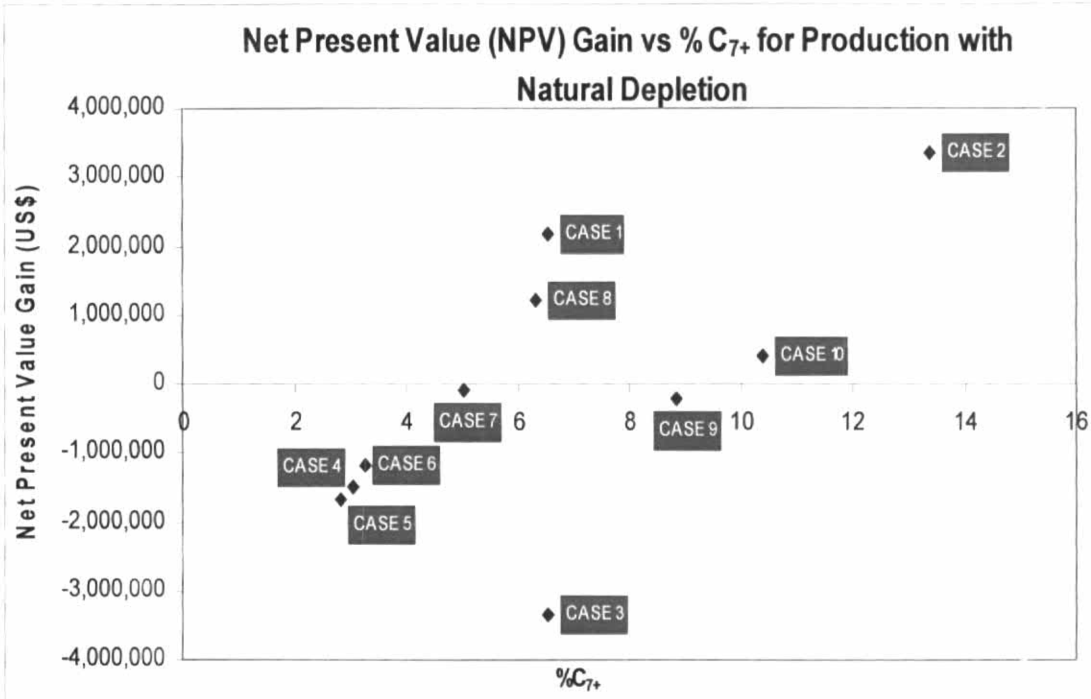


Figure 5.38: Net present value (NPV) gain by implementing gas cycling as a function of the mole percentage of C_{5+}.

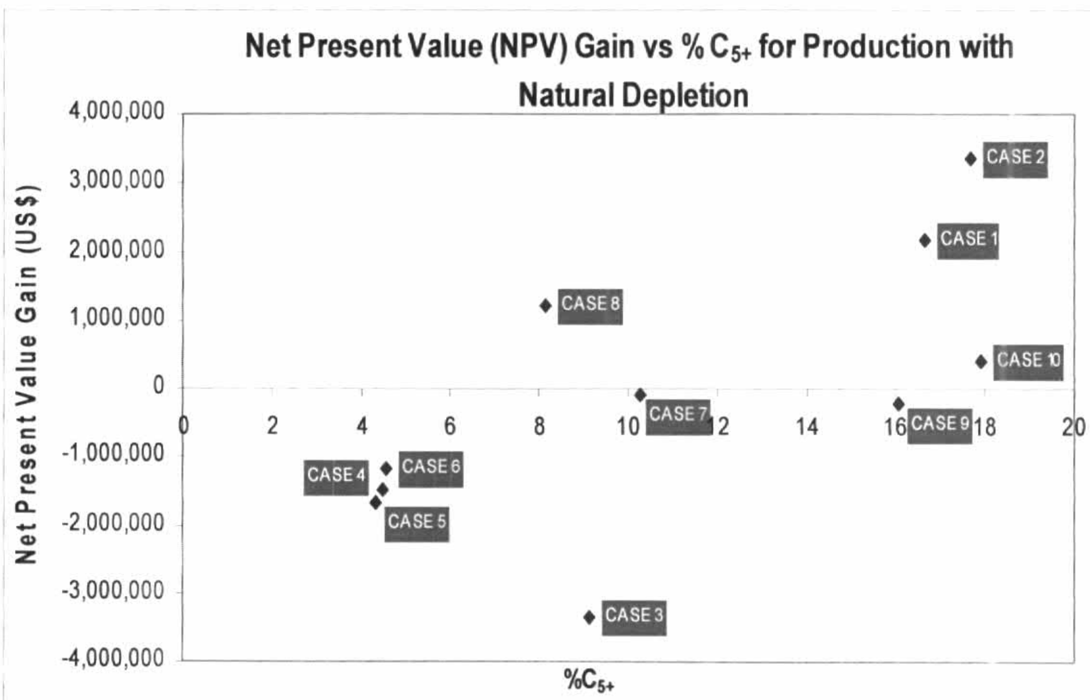


Figure 5.39: Net present value (NPV) gain by implementing gas cycling as a function of the mole percentage of C_{7+}.

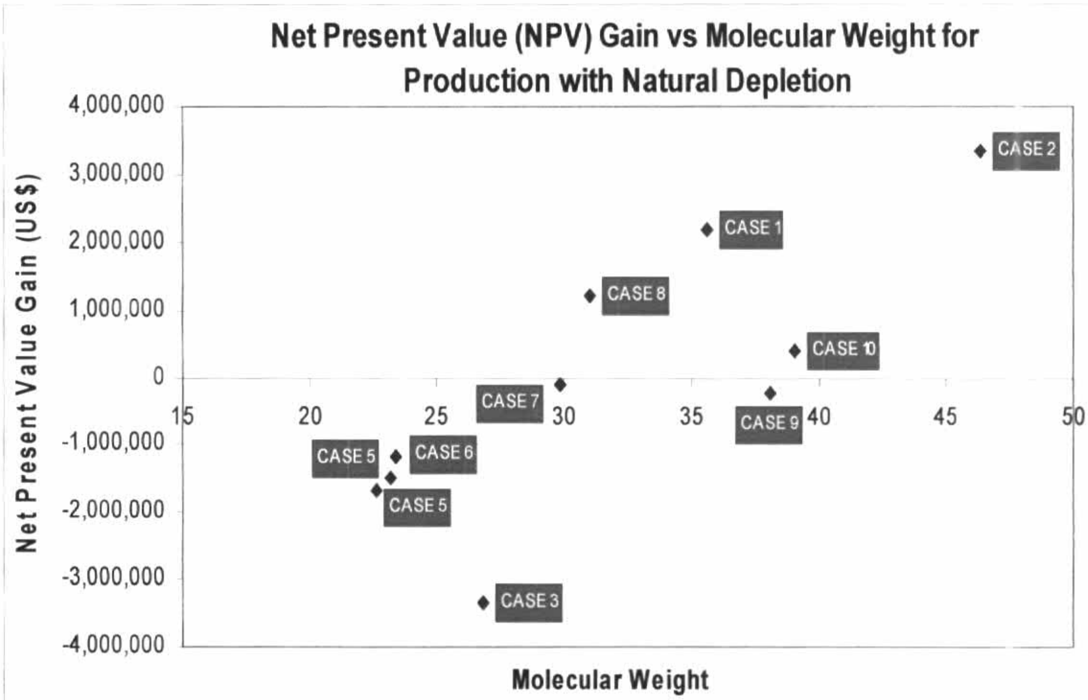


Figure 5.40: Net present value (NPV) gain by implementing gas cycling as a function of molecular weight of the composition.