

CHAPTER VI

EFFECTS OF PVT PROPERTIES OF OIL AND GAS

It was found from the results of simulation study in chapter V that a control of maximum allowable oil production rate does not have a significant impact to ultimate oil recovery from a natural depletion process of a solution gas drive reservoir. A numerical reservoir model having homogeneous properties and fluid set with initial solution gas oil ratio of 500 SCF/STB were used for these cases. A control of oil production rate does affect on time to reach ultimate oil recovery, i.e. the higher the maximum allowable oil production rate, the shorter the time to reach ultimate oil recovery. However, it was considered that this conclusion might be valid for a specific range of fluid properties. Therefore, it was decided to investigate the effects of fluid properties on the relationship between maximum allowable oil production rate and the ultimate oil recovery as well as on the time to reach that ultimate oil recovery.

PVT properties values are determined from the same correlations used for determining PVT properties of the base case. Table 6.1 contains properties values at bubble point pressure of two sets of fluid used for these investigations.

Note that initial reservoir pressure of each set is specified at 500 psia above bubble point pressure of oil. Table 6.2 summarizes fluid in place volumes at initial condition when each set of oil and gas is applied in the model.

Table 6.1 PVT properties of oil and gas used for investigating effect of PVT properties

Fluid set #	API	P_b (PSIA)	P_i (PSIA)	R_{si} (SCF/ STB)	B_o (RB/ STB)	μ_o (CP)	γ_g (AIR = 1.0)	B_g (RB/ MSCF)	μ_g (CP)
1	35	2,500	3,000	500	1.27	0.80	0.60	1.0476	0.019
2	50	2,500	3,000	1,000	1.51	0.23	0.67	0.9374	0.020

Table 6.2 Hydrocarbon fluid in place volumes at initial condition of reservoirs with fluid having different PVT properties

Fluid set #	OIP (MMSTB)	GIIP (MMMSCF)
1	9.77	4.89
2	8.92	8.92

It can be observed from table 6.2 that for a certain pressure difference between initial reservoir pressure and initial bubble point pressure, the reservoir having oil which has higher solution gas oil ratio has lower oil initially in place than that of the reservoir having lower solution gas oil ratio, provided that both reservoirs have equal pore volume. This is because oil which has higher initial solution gas oil ratio also has higher oil formation volume factor at bubble point pressure. Thus with the same

volume of oil in the reservoir, oil which has lower initial solution gas oil ratio will have larger volume at standard condition. In contrast, reservoir having oil with higher initial solution gas oil ratio has more gas initially in place than does the reservoir with lower initial solution gas oil ratio. This is because the same volume of the oil with higher initial solution gas oil ratio contains more gas compared to that of the oil with lower initial solution gas oil ratio.

The well is allowed to flow initially at its maximum allowable oil rate. This means the well can flow without limitation of gas production rate or of bottom hole pressure. Observations are made to oil flow rate, producing gas oil ratio, average reservoir pressure, bottom hole pressure, recovery of oil and of gas. The tubing head pressure is not observed since tubing lift curve is not included in the model. The only limitation of the production is the lower limit which is set to 50 STB/D for all cases.

Table 6.3 summarizes results observed from each run of individual fluid. The measurements are made at sand face with instantaneous transfer to the standard condition. Comparisons of recovery factor of the cases having fluids with different sets of R_{si} are illustrated in Figure 6.1 and 6.2.

From the table, it can be seen that for the cases which fluid set 1 which has R_{si} of 500 SCF/STB and initial reservoir pressure of 3,000 psia, maximum allowable oil production rate does not have significant impact on ultimate oil recovery. The highest maximum allowable oil rate which is 3,392 STB/D could be observed from case 2001. Maximum oil recovery from the model having R_{si} of 500 SCF/STB is recorded at 10.94%. The maximum difference of ultimate oil recovery of the model that has R_{si} of 500 SCF/STB is 1% which is found between the cases of 3,000 STB/D and 500

Table 6.3 Effects of fluid properties on the relationship between maximum allowable oil rate and ultimate oil recovery

Run No.	Fluid Set	Maximum allowable oil rate (STB/D)	Ultimate oil recovery (percent)	Time to reach ultimate oil recovery (days)	Avg. reservoir pressure at abandonment (psia)
2001	1	3,392	10.93	3341	612
2002	1	3,000	10.94	3,341	612
2003	1	2,500	10.93	3,341	612
2004	1	2,000	10.91	3,341	628
2005	1	1,500	10.92	3,341	616
2006	1	1,000	10.89	3,341	622
2007	1	800	10.88	3,441	625
2008	1	500	10.84	3,653	656
2009	2	9,884	16.17	3,653	438
2010	2	7,000	16.16	3,653	438
2011	2	5,000	16.14	3,653	439
2012	2	3,000	16.14	3,653	442
2013	2	1,000	16.10	3,653	466
2014	2	800	16.09	3,953	453
2015	2	500	16.16	4,853	454

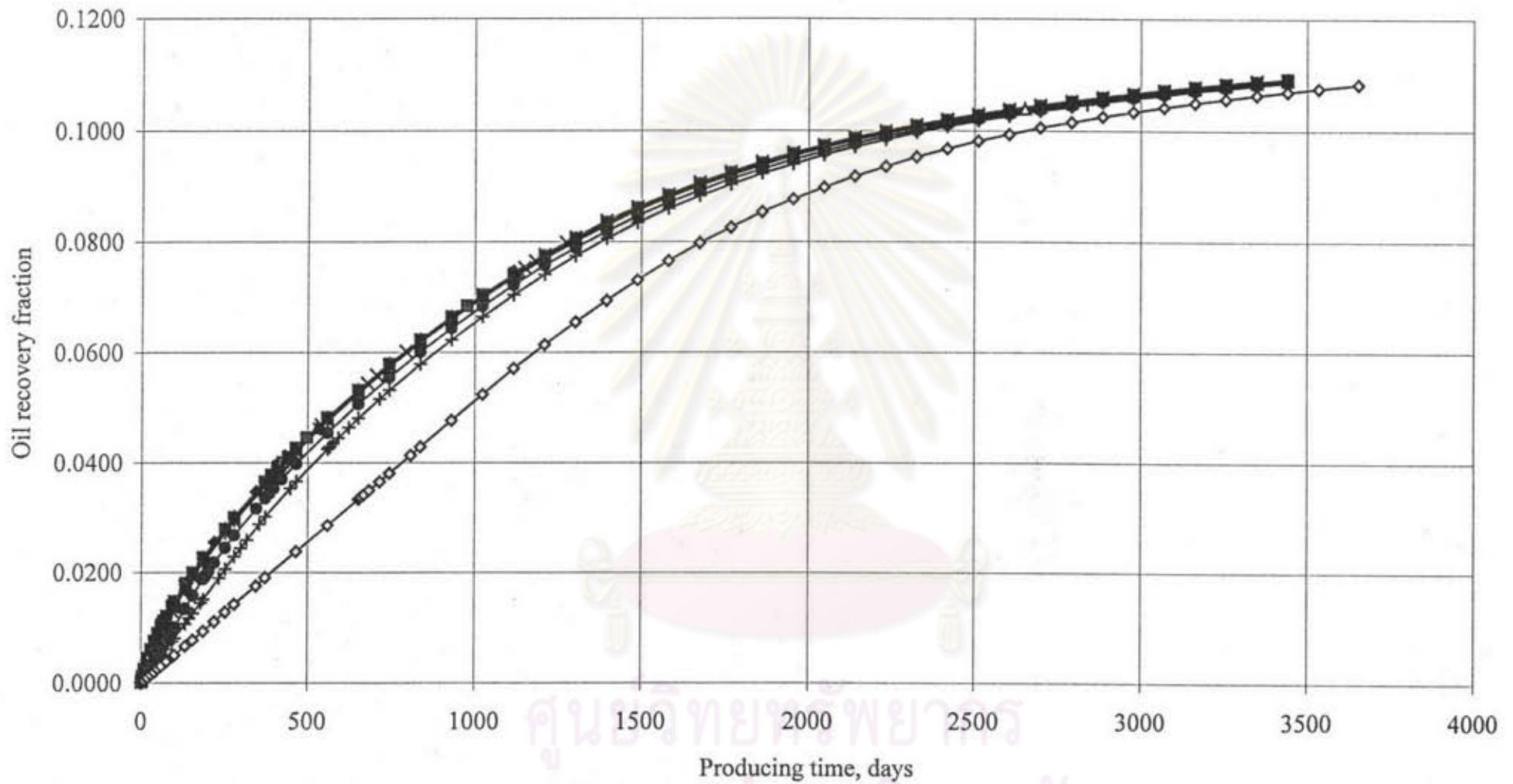


Figure 6.1 Oil recovery fraction of the cases having oil with initial solution gas oil ratio of 500 SCF/STB

Maximum allowable oil rate

◆ Q_o = 3391 STB/D ■ Q_o = 3000 STB/D ▲ Q_o = 2500 STB/D ✕ Q_o = 2000 STB/D * Q_o = 1500 STB/D ● Q_o = 1000 STB/D
 + Q_o = 800 STB/D ◇ Q_o = 500 STB/D

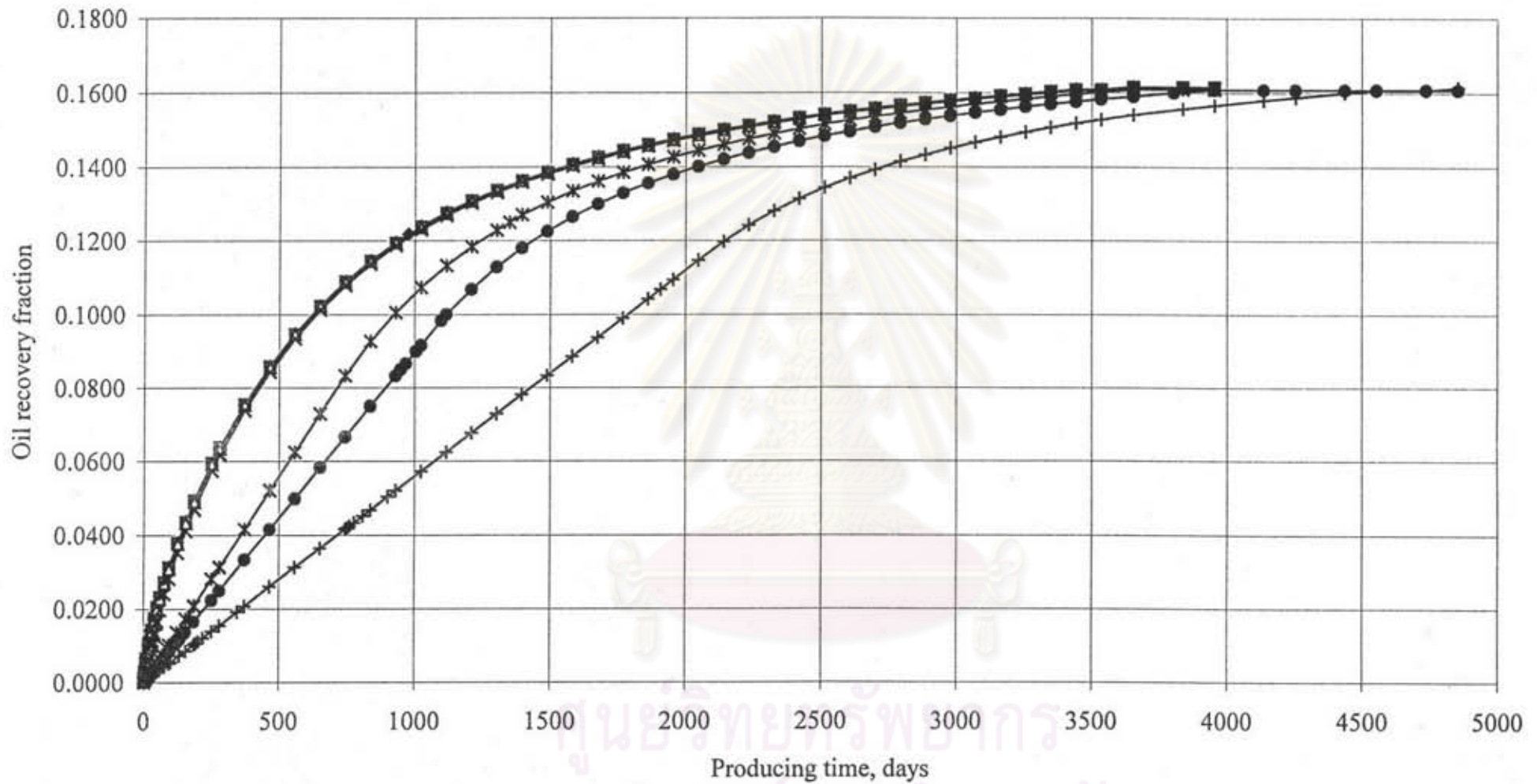


Figure 6.2. Oil recovery fraction of the cases having oil with initial solution gas oil ratio of 1,000 SCF/STB

Maximum allowable oil rate

◆ Q_o = 9884 STB/D ■ Q_o = 7000 STB/D ▲ Q_o = 5000 STB/D ✕ Q_o = 3000 STB/D * Q_o = 1000 STB/D ● Q_o = 800 STB/D + Q_o = 500 STB/D

STB/D. Furthermore, the average reservoir pressure after abandonment among eight cases are not much different. The magnitude of maximum pressure difference after abandonment is 45 psi. Note that six of the eight cases using the first fluid set have the same number of producing days for reaching its ultimate oil recovery, i.e., 3,341 days. The only cases which have longer producing days are the cases with maximum allowable oil rate of 800 STB/D and 500 STB/D. Times to reach ultimate oil recovery of the latter cases are 3,441 and 3,653 days respectively.

The second set of fluid is used in the same model to perform the second set of simulation studies. The first case of this group allows the well to produce at its maximum production rate of 9,884 STB/D. It is seen from this observation that the reservoir with oil having higher initial solution gas oil ratio has more energy than does the reservoir with oil having low initial solution gas oil ratio, provided that initial reservoir pressure and initial bubble point pressure of the two reservoirs are equal. Maximum oil recovery is observed in the case with 9,884 STB/D and is equal to 16.17%. The maximum difference of oil recovery is equal to 0.4%. Thus, it is considered the difference is negligible. Though oil recoveries of each run of this fluid set are slightly different for the cases with oil rates of 1,000 STB/D or greater, times to reach those ultimate oil recovery values are equal, i.e., at 3,653 days after the well started production. Times to reach ultimate oil recovery for the cases with maximum allowable oil rates of 800 and 500 STB/D are 3,953 and 4,853 days, respectively. The difference in average reservoir pressure is noticed from each case. The maximum average reservoir pressure at abandonment of natural depletion process is found from the case which maximum allowable oil rate is set to 1,000 STB/D. The maximum

difference in average reservoir pressure at abandonment is 28 psi found between case with 9,884 STB/D and 1,000 STB/D.

Figure 6.3 is a comparison of oil production rates of the cases having oil with initial solution gas oil ratio of 1,000 SCF/STB. Compared to Figure 5.1, both plots have similar curves but the plateau rate of each case in Figure 6.3 are longer. For instance, the case with 1,000 STB/D in Figure 6.3 has plateau rate for 750 days while the case with the equal maximum allowable oil rate in Figure 5.1 has plateau rate for 200 days.

Figure 6.4 is a plot of GOR of the cases having oil with initial solution gas oil ratio of 1,000 SCF/STB. It is seen in this figure that the curves of the cases with maximum allowable oil rate of 3,000 STB/D or greater have similar GOR curves while that of the case with 1,000 STB/D is different from other of the group during the first 2,500 days. These curves become similar after the well has produced for more than 2,500 days.

A plot of average reservoir pressure is shown in Figure 6.5. It is found that the case with maximum allowable oil rate of 500 STB/D has higher average reservoir pressure at almost any time. It is further noticed that the average reservoir pressure of the cases having maximum allowable oil rate of 1,000 STB or smaller inversely relates to maximum allowable oil rate. The higher the maximum allowable oil rate, the lower the average reservoir pressure. For the cases with maximum allowable oil rate of 1,000 STB/D or greater, average reservoir pressures are not much different. Average reservoir pressure of each case is close at the abandonment.

Consider Figure 6.6 which is a comparison of ultimate oil recovery obtained from of the cases with the same maximum allowable oil rate of 1,000 STB/D but

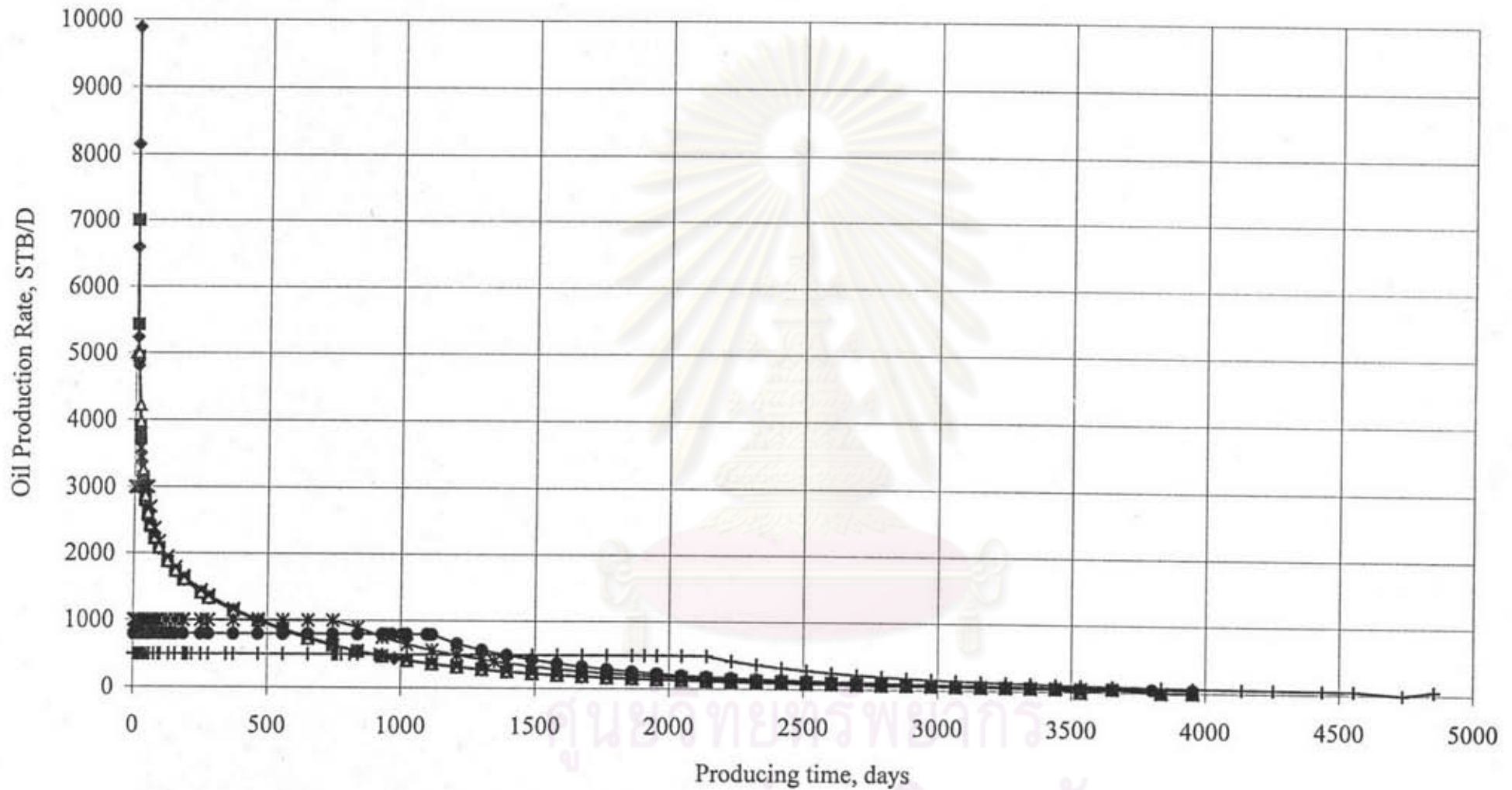


Figure 6.3 Oil production rate of the cases having oil with initial solution gas oil ratio of 1,000 SCF/STB

Maximum allowable oil rate

◆ $Q_o = 9884$ STB/D ■ $Q_o = 7000$ STB/D ▲ $Q_o = 5000$ STB/D ✕ $Q_o = 3000$ STB/D * $Q_o = 1000$ STB/D ● $Q_o = 800$ STB/D + $Q_o = 500$ STB/D

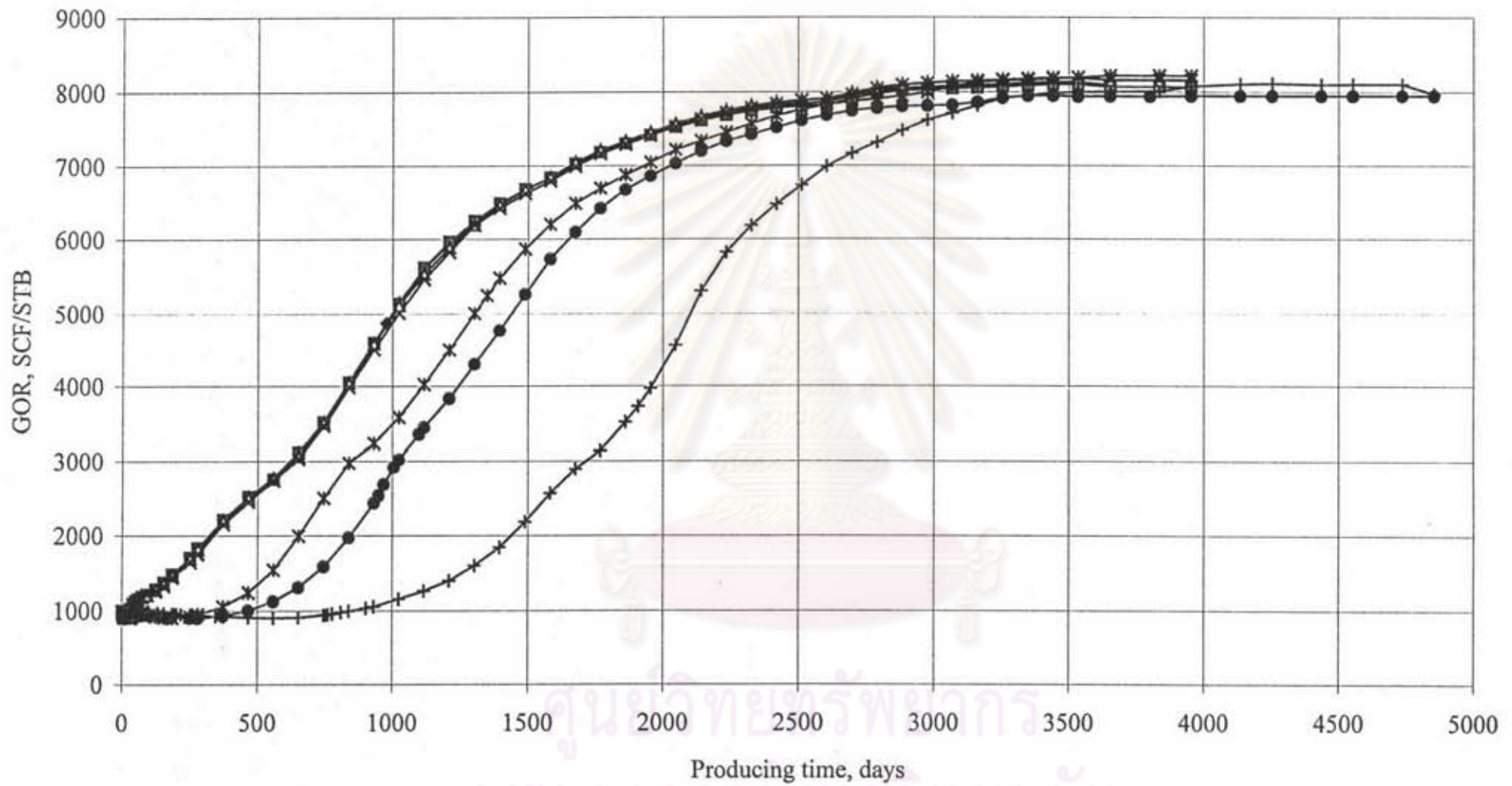


Figure 6.4 GOR of the cases having oil with initial solution gas oil ratio of 1,000 SCF/STB

Maximum allowable oil rate

◆ Qo = 9884 STB/D ■ Qo = 7000 STB/D ▲ Qo = 5000 STB/D ✕ Qo = 3000 STB/D * Qo = 1000 STB/D ● Qo = 800 STB/D + Qo = 500 STB/D

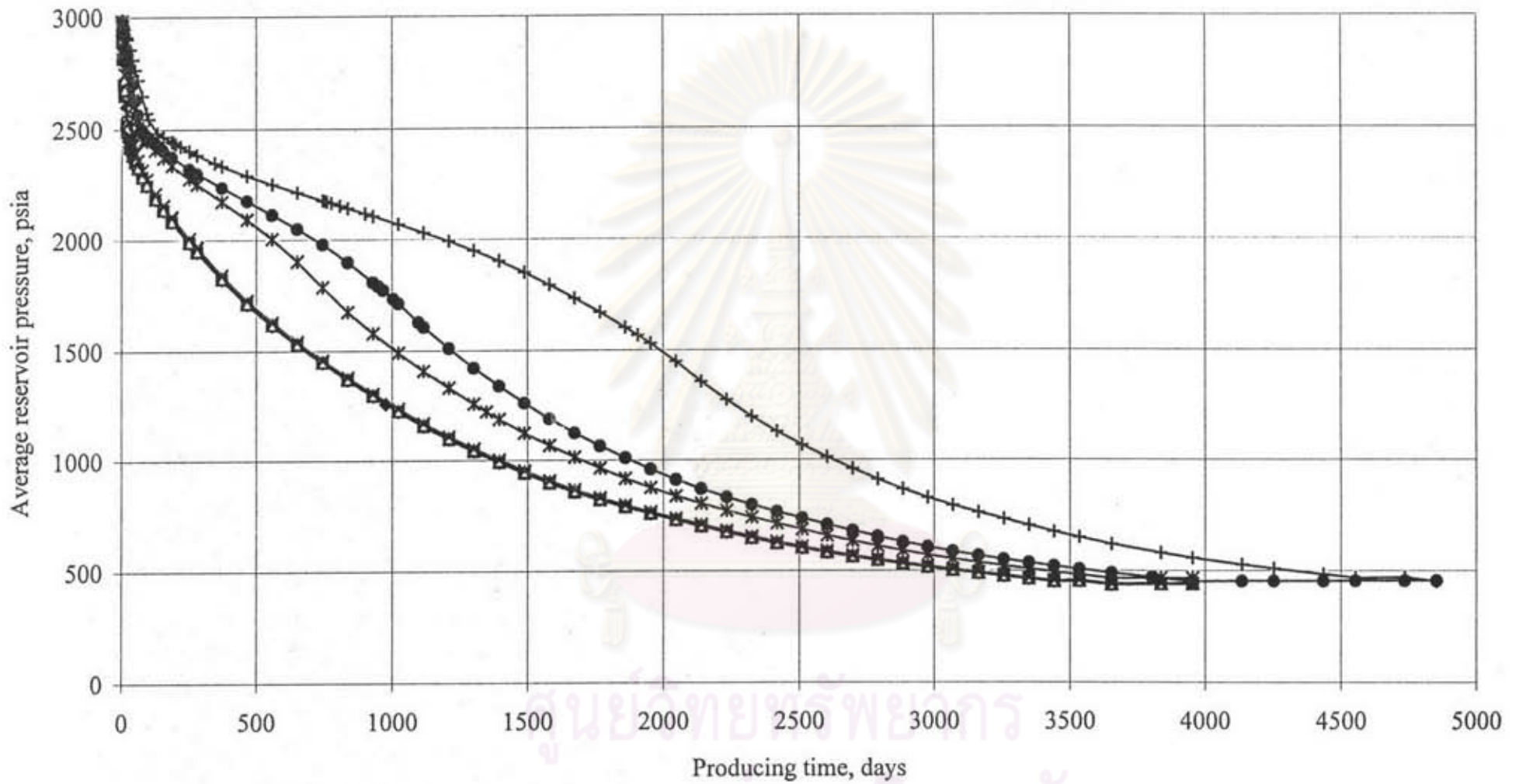


Figure 6.5 Average reservoir pressure of the cases having oil with initial solution gas oil ratio of 1,000 SCF/STB

Maximum allowable oil rate

◆ Qo = 9884 STB/D
 ■ Qo = 7000 STB/D
 ▲ Qo = 5000 STB/D
 ✕ Qo = 3000 STB/D
 * Qo = 1000 STB/D
 ● Qo = 800 STB/D
 + Qo = 500 STB/D

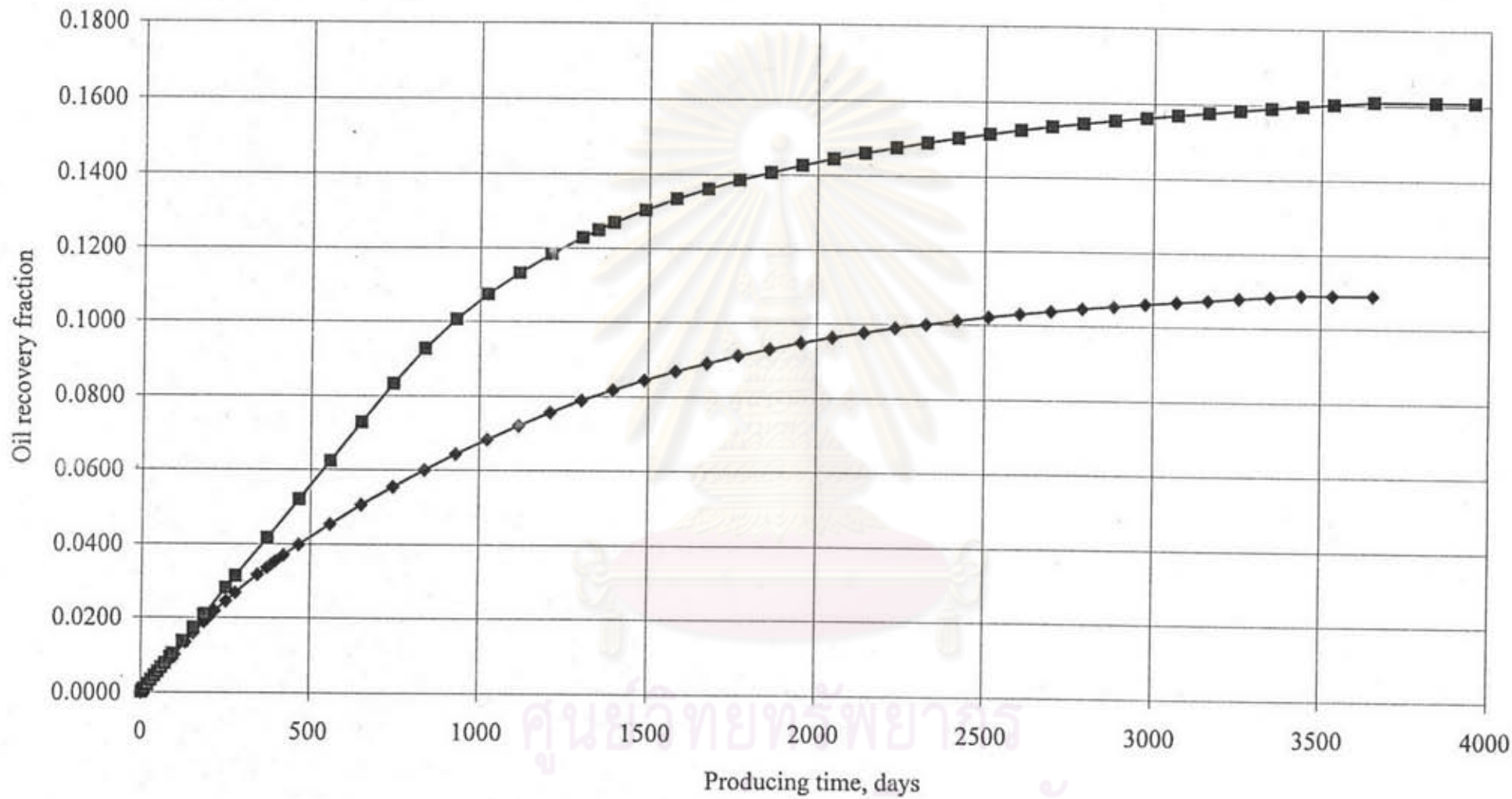


Figure 6.6 Oil recovery fraction of the cases having oil with initial oil production rate of 1000 STB/D

◆ Rsi = 500 SCF/STB ■ Rsi = 1000 SCF/STB

having different PVT properties. It could be seen from this figure that ultimate oil recovery from reservoir having oil with higher initial solution gas oil ratio is higher than that from the reservoir having oil with lower initial solution gas oil ratio. The higher ultimate oil recovery is the result of higher cumulative production as seen in Figure 6.7 rather than the result of having lower oil initially in place. Note that these two reservoirs have equal initial reservoir and initial bubble point pressures.

From the investigations in chapter V and in this chapter, it could be concluded that fluid properties do not have any effect on the relationship between maximum allowable oil rate and ultimate oil recovery for a homogeneous reservoir having solution gas drive mechanism. That is, the maximum allowable oil rate does not have any significant impact on the ultimate recovery even if the properties of fluids are different. In addition, it can be concluded that the reservoir with oil having higher initial solution gas oil ratio has higher ultimate recovery, provided that initial reservoir and initial bubble point pressures of oil are equal.

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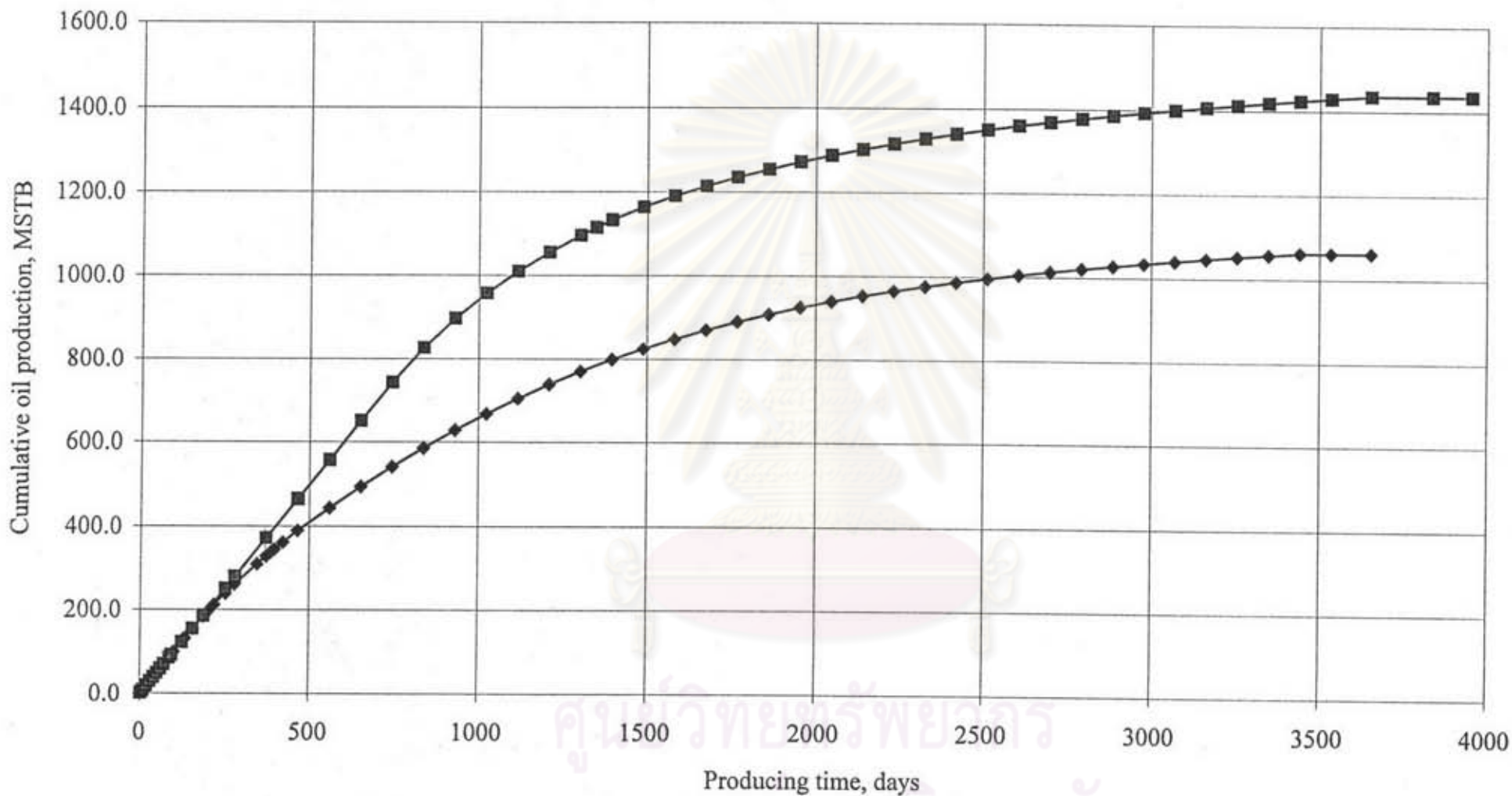


Figure 6.7 Cumulative oil production from the cases having oil with initial oil production rate of 1,000 STB/D

—◆— $R_{si} = 500$ SCF/STB —■— $R_{si} = 1000$ SCF/STB