CHAPTER VII

EFFECTS OF RESERVOIR HETEROGENEITY

It was found in chapter V and chapter VI that effect of maximum allowable oil rate on ultimate oil recovery of solution gas drive reservoir producing under natural depletion process was insignificant. It did have effect on time to reach that ultimate oil recovery as well as recovery at various time points, though. However, a homogenous and isotropic numerical reservoir model was used for investigations in those chapters. This type of reservoirs is, in fact, not existent in reality. All of the actual reservoirs are heterogeneous. Therefore, it is imperative to investigate if the heterogeneity has any effect on the relationship between the oil production rate and ultimate oil recovery.

To create the heterogeneous reservoir for the simulation run, different values of porosity assigned to various simulation blocks were generated from a normal distribution curve. The values for permeability assigned to various blocks were generated from a log normal distribution curve.

In general, the probability distribution of porosity mostly found is normally distributed and the probability distribution of permeability is log normally distributed. Thus programs for generating these types of distribution were developed and the results are used in the model. A set of normal distribution was used to generate porosity values while three sets of log normal distributions were used to generate permeability values. The set of normal distribution of porosity has mean of 20% and standard deviation of 5%. Table 7.1 summarizes distribution parameters for permeability sets used in the model.

Table 7.1 Mean and standard deviation of permeability sets used for investigating

effect of reservoir heterogeneity

Permeability set	Natural log of Mean	Natural log of SD
1	4.605	1.00
2	4.605	1.25
3	4.605	1.50

Figure 7.1 represents normal distribution curve of porosity used in the model

for all investigations conducted in this chapter. Figure 7.2 to 7.4 are the plots of log

normal distribution of effective permeability set 1 to set 3, respectively.

In this model, a fluid set having oil which has solution gas oil ratio of 1,500

SCF/STB has been used. In addition, API gravity of oil is 55 degree and its bubble

point pressure is 3,000 psia. At its bubble point pressure, this oil has formation volume

factor of 1.61 RB/STB and viscosity of 0.20 cp. Hydrocarbon gas in this model has

specific gravity of 0.65 while specific gravity of air is 1.00. At 3,000 psia, this gas has

formation volume factor of 0.8481 RB/MSCF. At initial condition the reservoir has

pressure of 3,500 psia, and OIIP of 8.57 MMSTB and GIIP of 12.86 MMMSCF.

Table 7.2 summarizes the results obtained from the cases for investigation of

the effect of reservoir heterogeneity. Figure 7.5 to 7.7 illustrate comparison of

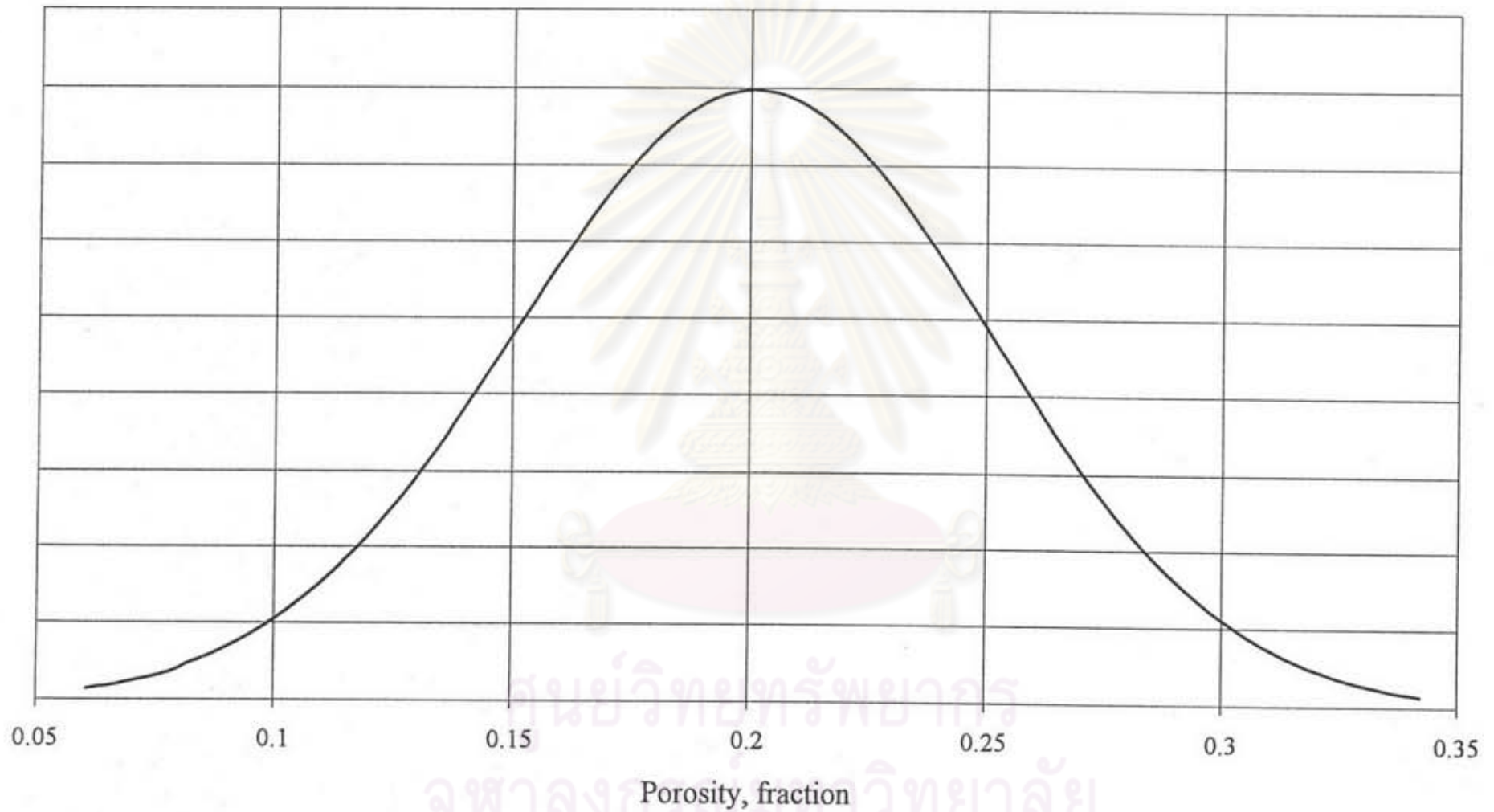recoveries of oil obtained from each group.

Figure 7.1 Normal distribution of porosity having means of 0.20 and standard deviation of 0.05
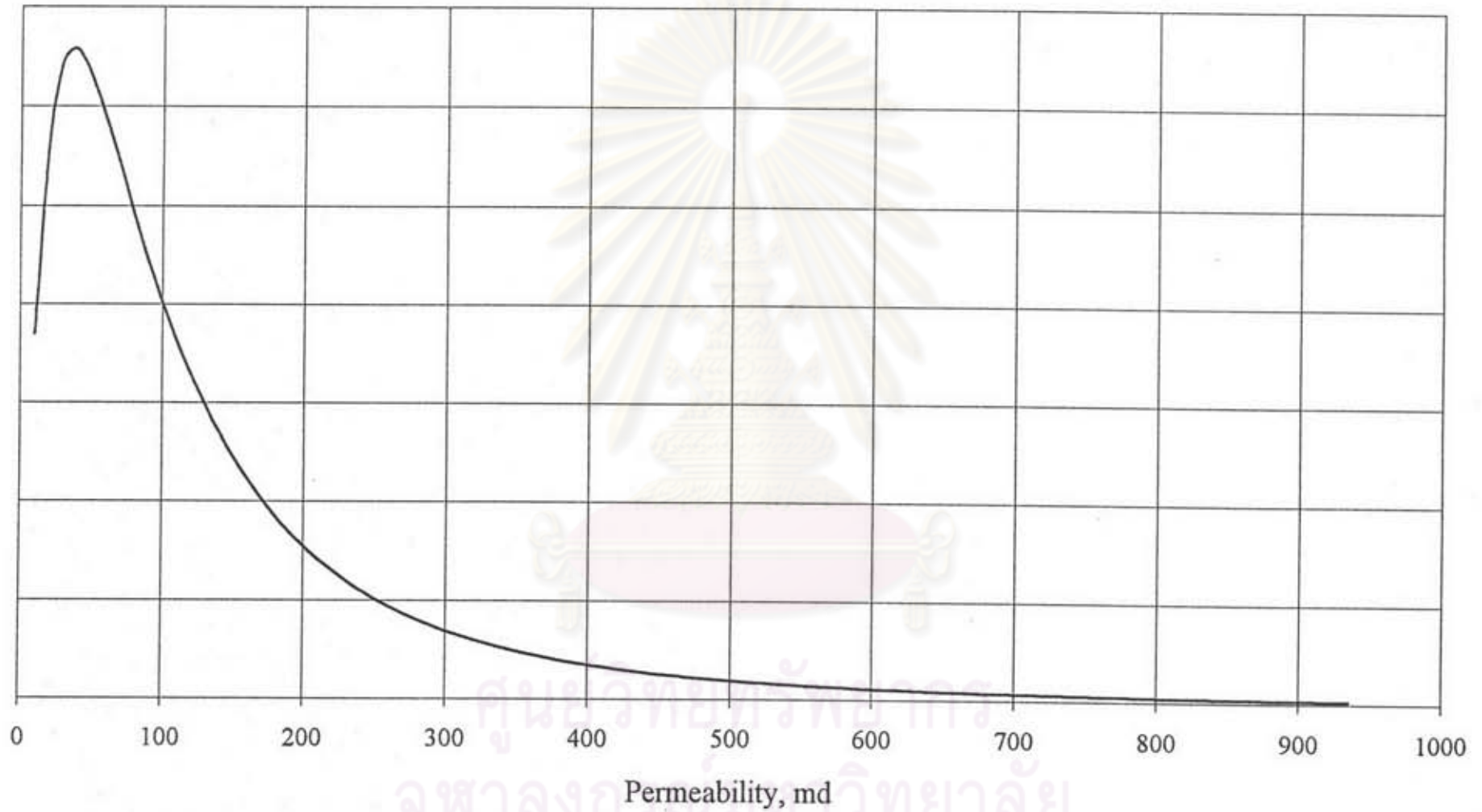
Figure 7.2 Log normal distribution of permeability having means of 4.605 and standard deviation of 1.00
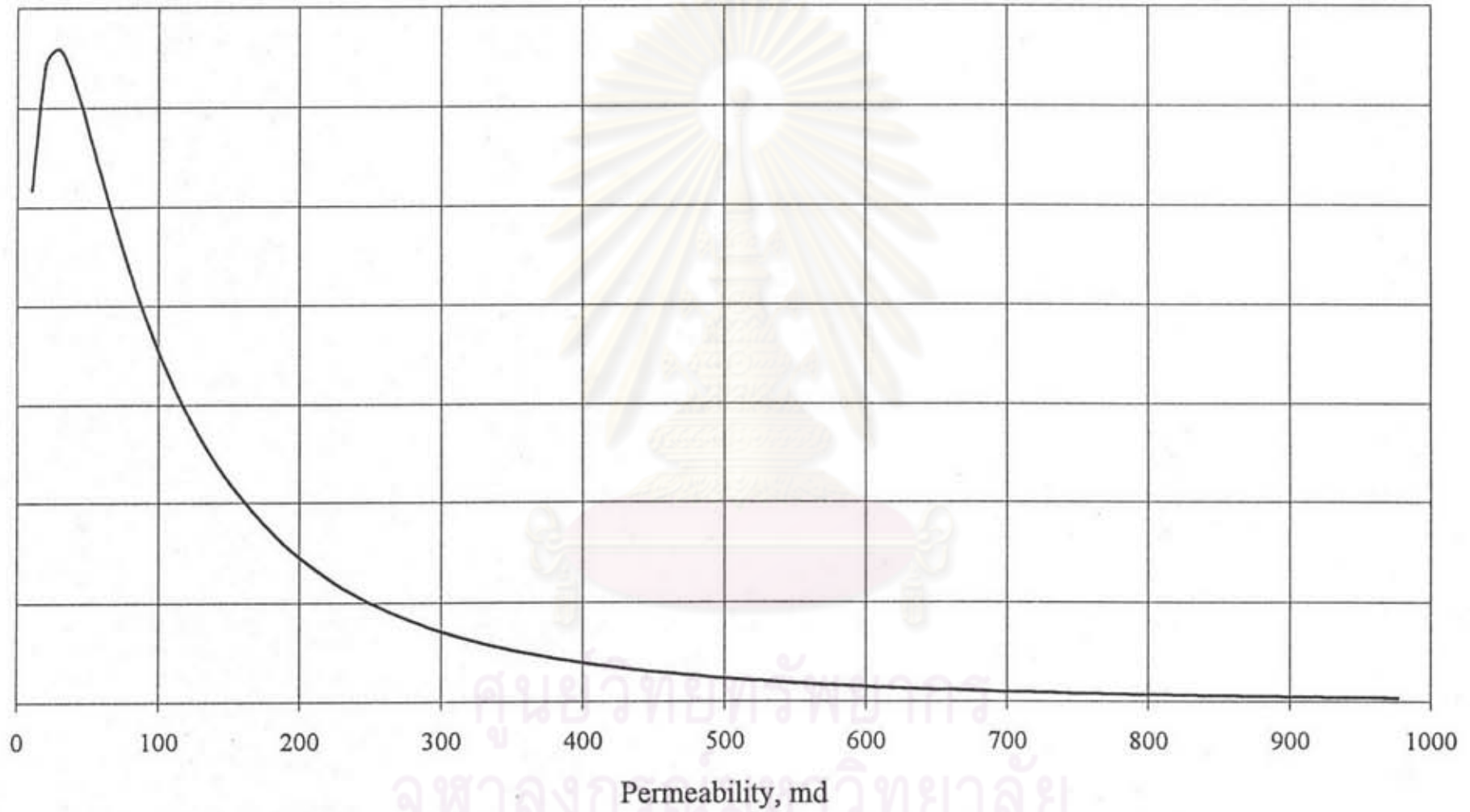
Figure 7.3 Log normal distribution of permeability having means of 4.605 and standard deviation of 1.25
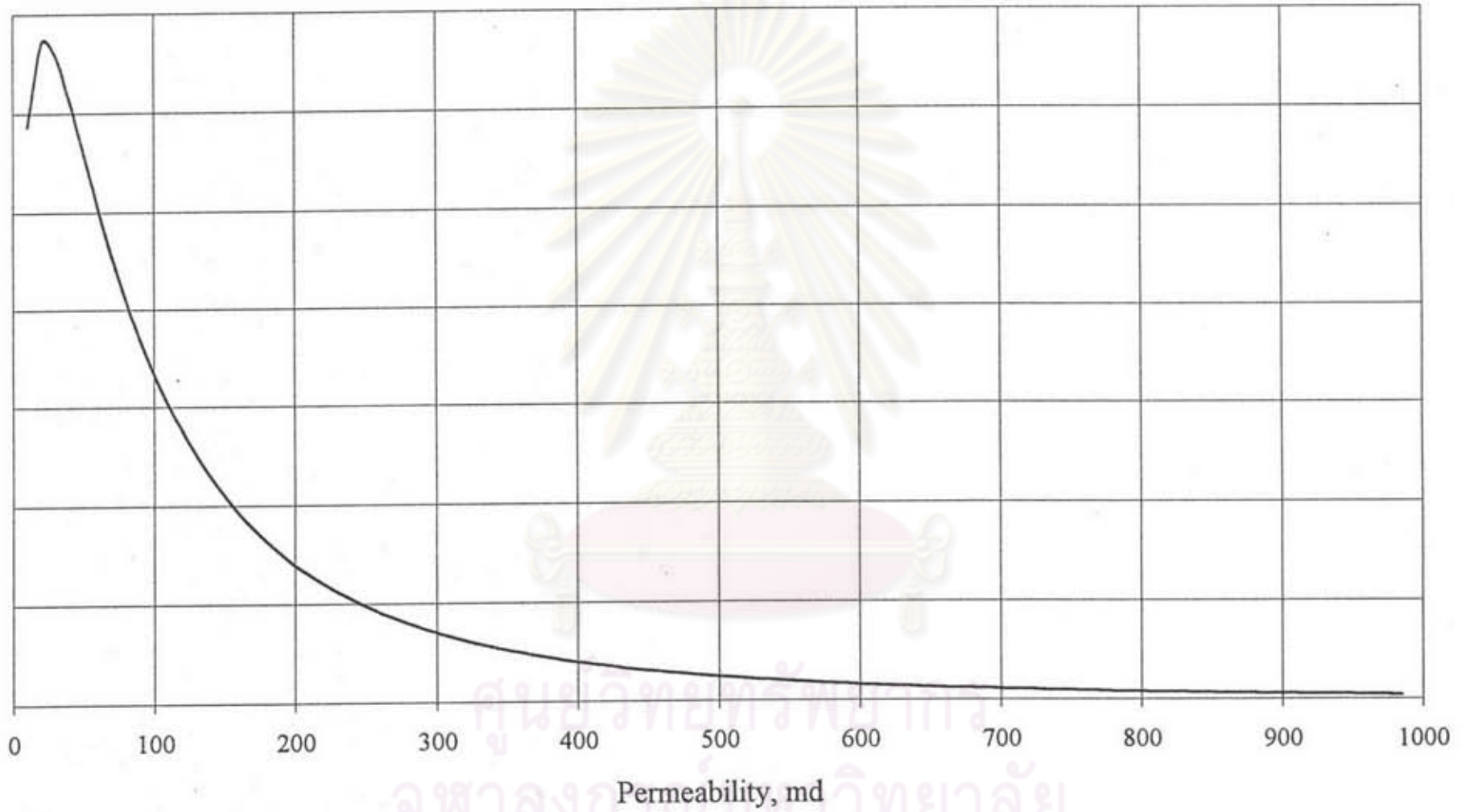
Figure 7.4 Log normal distribution of permeability having means of 4.605 and standard deviation of 1.50

Table 7.2 Effects of heterogeneity on the relationship between maximum allowable oil

rate and ultimate oil recovery

Run No.	Permeability Set	Maximum allowable oil rate (STB/D)	Ultimate Oil recovery (percent)	Time to reach ultimate oil recovery (days)	Avg. reservoir pressure at Abandonment (psia)
3001	1	14,750	16.26	3,534	346
3002	1	8,000	16.20	3,348	364
3003	1	5,000	16.31	3,534	347
3004	1	3,000	16.19	3,441	369
3005	1	1,000	16.26	3,953	340
3006	1	500	16.33	4,853	374
3007	2	11,007	15.89	3,653	457
3008	2	8,000	15.77	3,653	482
3009	2	5,000	15.81	3,953	469
3010	2	3,000	15.74	3,534	493
3011	2	1,000	15.72	3,534	516
3012	2	500	15.80	4,553	531

Table 7.2 Effects of heterogeneity on the relationship between maximum allowable oil

rate and ultimate oil recovery (continued)

Run No.	Permeability Set	Maximum allowable oil rate (STB/D)	Ultimate Oil recovery (percent)	Time to reach ultimate oil recovery (days)	Avg. reservoir pressure at abandonment (psia)
3013	3	11,721	14.50	3,653	558
3014	3	8,000	14.53	3,953	551
3015	3	5,000	14.53	3,953	561
3016	3	3,000	14.51	3,653	560
3017	3	1,000	14.43	3,653	581
3018	3	500	14.34	3,953	653

The set of permeability having log normal distribution having natural logarithm

of mean of 4.605 and natural logarithm of standard deviation of 1.00 is used in the first

group of the investigations. It can be seen from Table 7.2 that ultimate recovery of oil

ranges from 16.19% to 16.33%. Figure 7.5 shows that oil recovery of each case in

this group at various producing time is approximately equal except that of the case

which has maximum allowable oil rate of 1,000 STB/D or smaller. Average reservoir

pressure at abandonment of each case varies between 340 to 374 psia. The difference

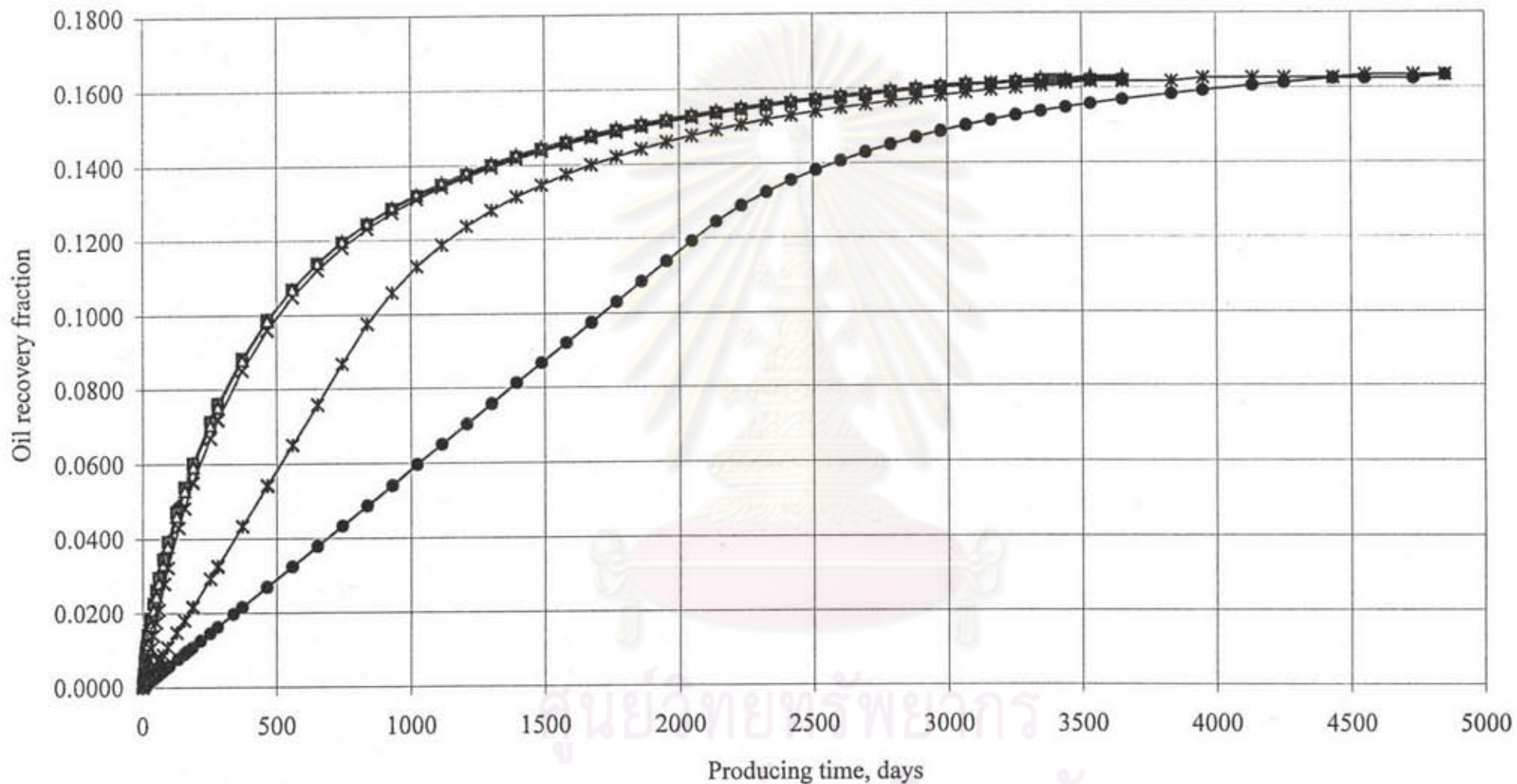of average reservoir pressure at abandonment is insignificant.

Figure 7.5 Oil recovery fraction of the cases in the reservoir with normal distribution porosity and
log normal permeability set#1

Maximum allowable oil rate

◆ Qo = 14750 STB/D ■ Qo = 8000 STB/D △ Qo = 5000 STB/D ✕ Qo = 3000 STB/D ✳ Qo = 1000 STB/D ● Qo = 500 STB/D

The simulation results from the second group use the same porosity distribution used in the previous model but different permeability set. The second group use the permeability set which has natural logarithm of standard deviation of 1.25. Figure 7.6 represents oil recovery obtained from each case in this group. Ultimate oil recovery of each case ranges from 15.72 to 15.89%. Recovery fraction of each case has similar shape to that of the first group. The case which has the lowest maximum allowable oil rate has the lowest recovery factor at every producing time point. Average reservoir pressure at abandonment of each case varies from 482 to 531 psia.

The similar behavior is observed for the cases in the third group where natural logarithm of standard deviation of permeability used is changed to 1.50. Ultimate oil recovery ranges from 14.34 to 14.50%. Figure 7.7 is a comparison of oil recovery of the case in this group. The case which has the lowest maximum allowable oil rate has a distinct behavior of recovery factor from the other cases in this group. Average reservoir pressure at abandonment ranges from 551 to 653 psia.

It could be then concluded that maximum allowable oil production rates do not have significant effects on ultimate oil recovery of depletion process of a heterogeneous reservoir. Another observation is that the cases which have production rates set equal to or greater than a certain maximum allowable oil rate have similar curves of oil recovery fraction plotted against producing time. Concerning average reservoir pressure at abandonment, it could be seen that the magnitudes of the average reservoir pressure at abandonment of the cases in each group vary in a narrow range. All these indicate that heterogeneity of a reservoir has insignificant effects on the relationship between maximum allowable oil rate and ultimate oil recovery.
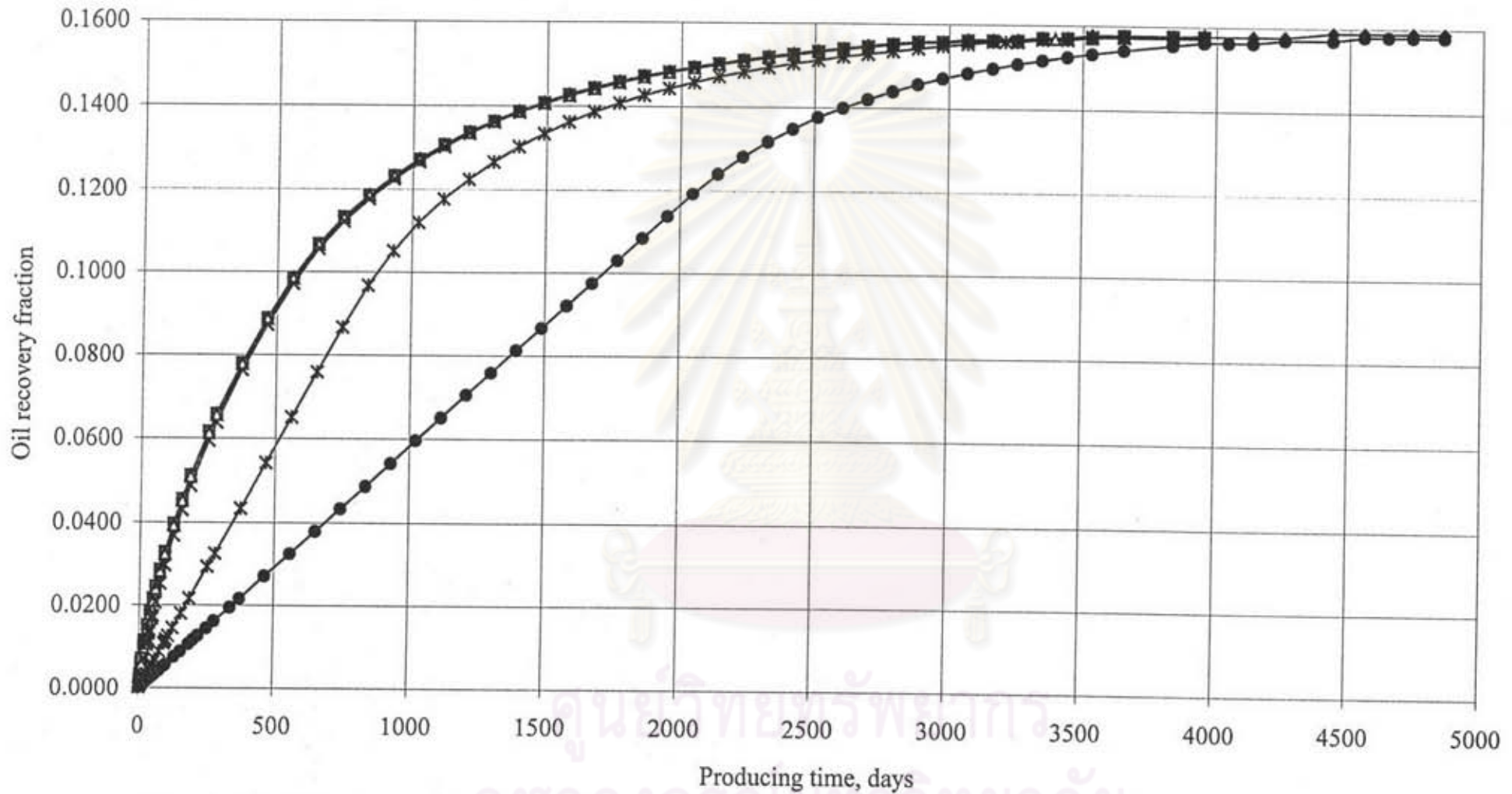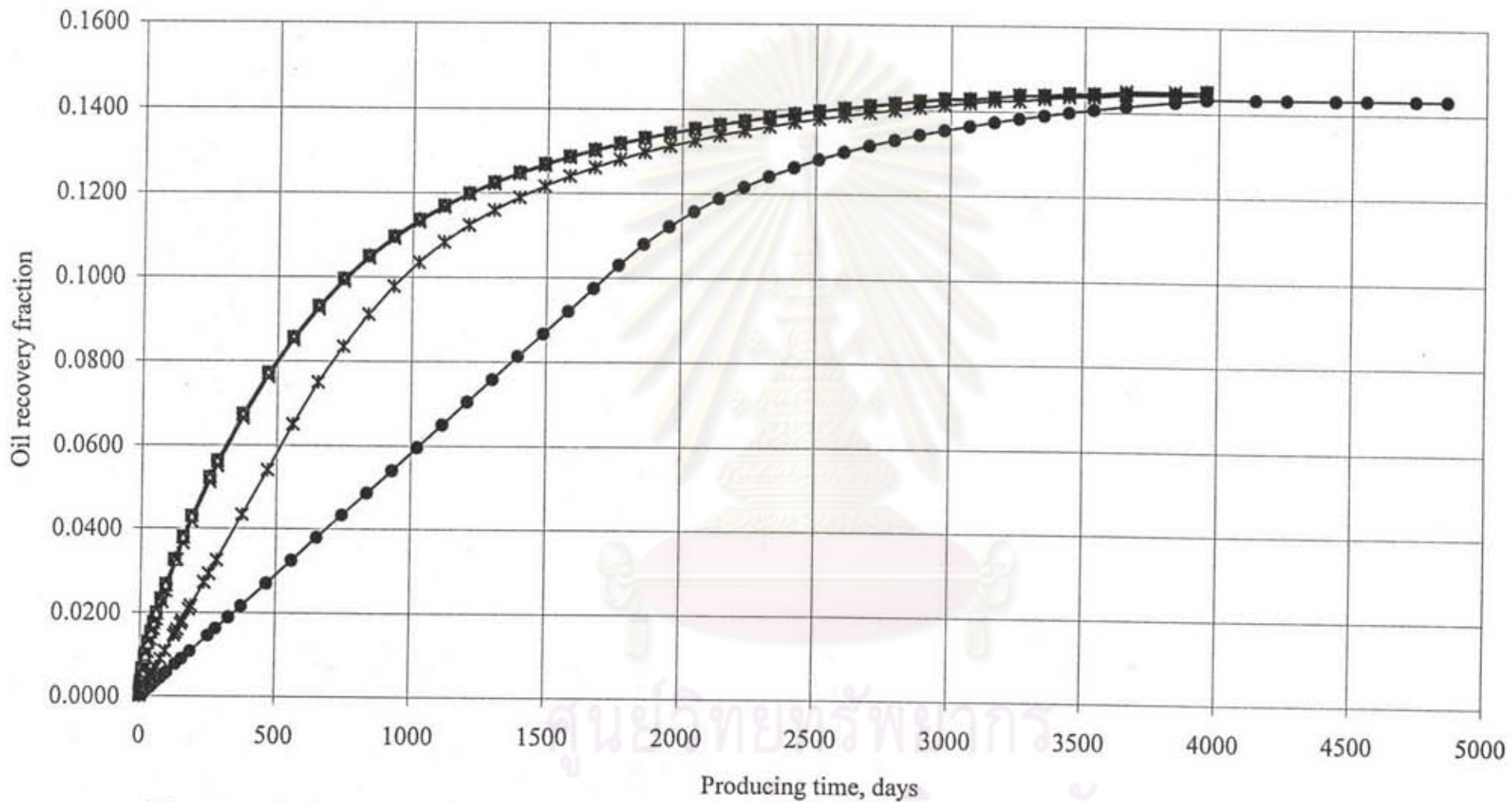
Figure 7.6 Oil recovery fraction of the cases in the reservoir with normal distribution porosity and
log normal permeability set#2

Maximum allowable oil rate

—◆—Qo = 11007 STB/D —■—Qo = 8000 STB/D —△—Qo = 5000 STB/D —✕—Qo = 3000 STB/D —✱—Qo = 1000 STB/D —●—Qo = 500 STB/D

Figure 7.7 Oil recovery fraction of the cases in the reservoir with normal distribution porosity and
log normal permeability set#3

Maximum allowable oil rate

♦—Qo = 11721 STB/D —■—Qo = 8000 STB/D —△—Qo = 5000 STB/D —✕—Qo = 3000 STB/D —✳—Qo = 1000 STB/D —●—Qo = 500 STB/D

Figure 7.8 shows oil recovery fraction at various producing time. All cases have maximum allowable oil rate of 3,000 STB/D. The group with natural logarithm of standard deviation of 1.00 has ultimate recovery about 16.3% while the groups with natural logarithm of standard deviation of 1.25 and 1.50 have ultimate oil recovery of about 15.8% and 14.5%, respectively. Therefore, it can be concluded from this figure that ultimate oil recovery from the reservoir with low heterogeneity is higher than that of the reservoir with high heterogeneity.
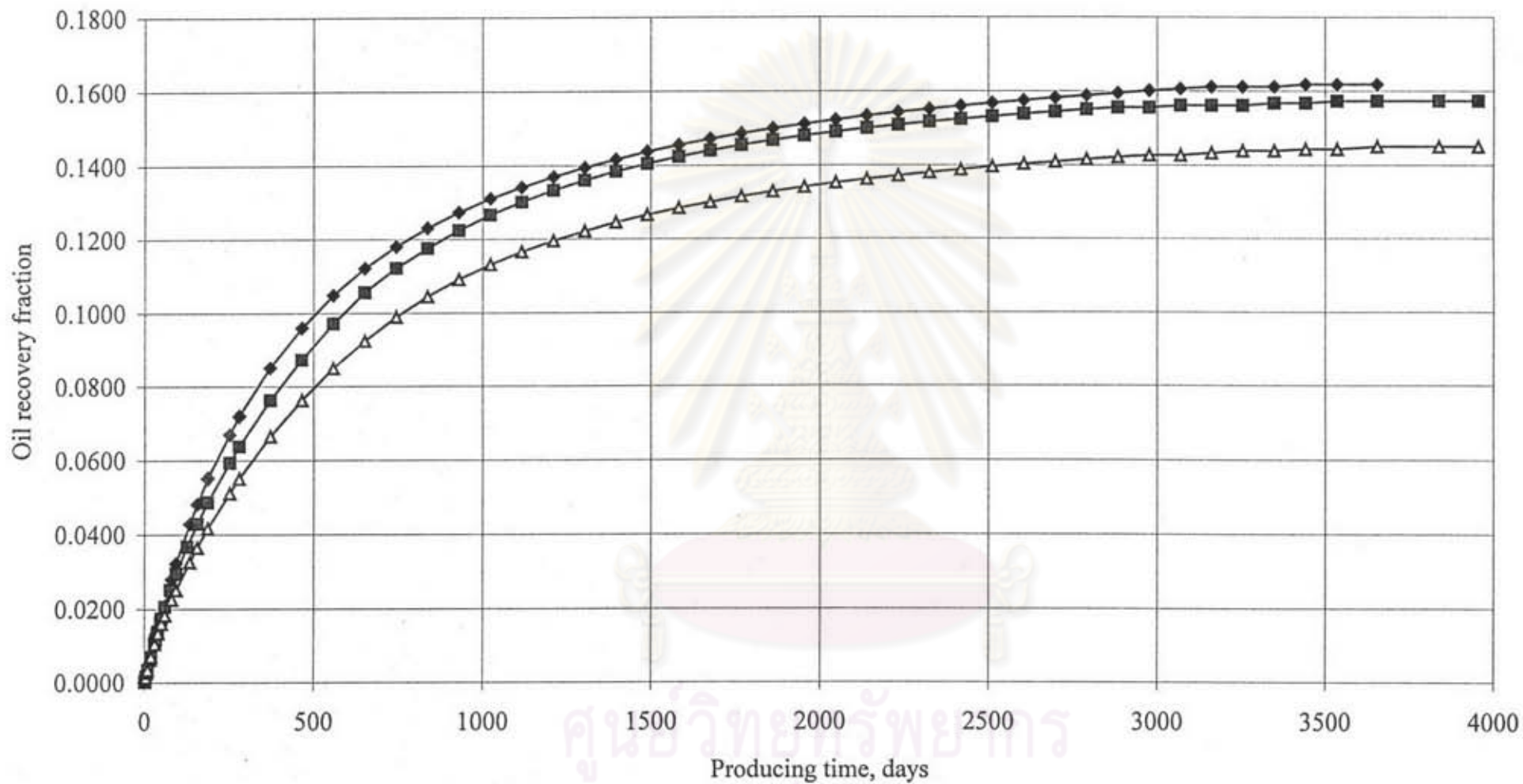
Figure 7.8 Oil recovery fraction of the cases with 3,000 STB/D in the reservoirs with normal distribution porosity and different log normal permeability