CHAPTER VIII

PRODUCTION CONTROL FOR OPTIMUM RECOVERY

It has been found from the previous three chapters that the maximum allowable oil production rate does not have significant impact on the magnitude of ultimate oil recovery of the depletion process of a solution gas drive reservoir. This conclusion is applicable to the cases of different fluid properties and the cases of heterogeneous reservoirs. However, those observations were made at the sand face where effects of fluid flow in tubing was excluded. In reality, tubing is always included in the production system. Therefore, the effects of multiphase flow in the tubing must be considered, in order to simulation the real production system.

To investigate the effects of fluid flow in pipe on the production process, a tubing lift curve table is included in the model. A tubing lift curve table is generated from a commercial software for computing flow in pipe variables included in the same package as the black oil simulator. As a tubing lift curve is included in the numerical reservoir model, flowing tubing head pressure can be observed.

The limitation of a number of data points of the tubing lift curve included in the model is the factor for selecting set of PVT properties of fluid used in the model. According to its limitation, a set of fluids having oil with initial solution gas oil ratio of 500 SCF/STB is used.

The results of various runs with different maximum allowable rates and different minimum flowing tubing head pressures, of 50, 100, and 150 psia, are shown

Table 8.1 Results of various runs with different minimum flowing tubing head pressure

Run No.	Minimum Flowing Tubing Head Pressure (psia)	Maximum allowable oil rate (STB/D)	Ultimate oil recovery (percent)	Time to reach ultimate oil recovery (days)	Avg. reservoir pressure at abandonment (psia)
4001	50	2725	10.56	3441	851
4002	50	2500	10.57	3441	849
4003	50	2300	10.56	3441	850
4004	50	2000	10.58	3441	851
4005	50	1500	10.55	3441	850
4006	50	1000	10.55	3441	857
4007	50	500	10.53	3653	876
4008	50	300	10.64	4553	872
4009	50	100	4.97	4853	2193
4010	100	2584	10.46	3441	901
4011	100	2300	10.48	3441	900
4012	100	2000	10.55	3653	876
4013	100	1500	10.53	3653	877

Table 8.1 Results of various runs with different minimum flowing tubing head pressure (continued)

Run No.	Minimum Flowing Tubing Head Pressure (psia)	Maximum allowable oil rate (STB/D)	Ultimate oil recovery (percent)	Time to reach ultimate oil recovery (days)	Avg. reservoir pressure at abandonment (psia)
4014	100	1000	10.51	3653	879
4015	100	500	10.51	3953	893
4016	100	300	10.56	4553	917
4017	150	2488	10.47	3653	927
4018	150	2000	10.47	3653	927
4019	150	1500	10.48	3653	926
4020	150	1000	10.43	3534	939
4021	150	500	10.38	3653	968
4022	150	300	10.50	4553	951

in Table 8.1. It can be observed from this table that ultimate oil recovery of each group, with the same minimum flowing tubing head pressure, is close to those of the other groups. This implies that a control of minimum flowing tubing head pressure does not have significant effect on the magnitude of ultimate oil recovery of a certain

gas drive reservoir. However, the ultimate oil recovery mentioned here is at the end of natural depletion process.

A set of simulation results which minimum flowing tubing head pressure is limited to 50 psia reveals that oil production rates of the cases with maximum allowable oil production rate of 1,000 STB/D or greater become similar as the well has been producing for a certain number of days, as shown in Figure 8.1. For example, oil flow rate for the cases with maximum allowable oil rate of 1,500 STB/D or greater becomes similar in 150 days while oil rate for the case with maximum allowable oil rate of 1,000 STB/D becomes similar to those of this group as the well has been producing for 360 days. Oil production rates of the cases with maximum allowable oil rate of 500 STB/D or lower start to decline later. However, the decline rates of the latter cases are similar to those of the group of maximum allowable oil rate of 1,000 STB/D or greater.

GOR plots (Figure 8.2) based on minimum flowing tubing head pressure of 50 psia show the similar shape among the cases having maximum allowable oil rate of 1,000 STB/D or greater. The plots of GOR of the cases in this group follow the behavior of a typical solution gas drive reservoir. GOR becomes lower than R_{si} as the well has been producing for short time because gas liberating from oil during this time is immobile. Once gas saturation in the reservoir becomes greater than critical gas saturation, gas starts to move resulting in the increasing of GOR. In the case with maximum allowable oil rate of 500 STB/D or lower, the change of GOR delays but the shape of these curves look similar to that of the cases with maximum allowable oil rates of 1,000 STB/D or greater.

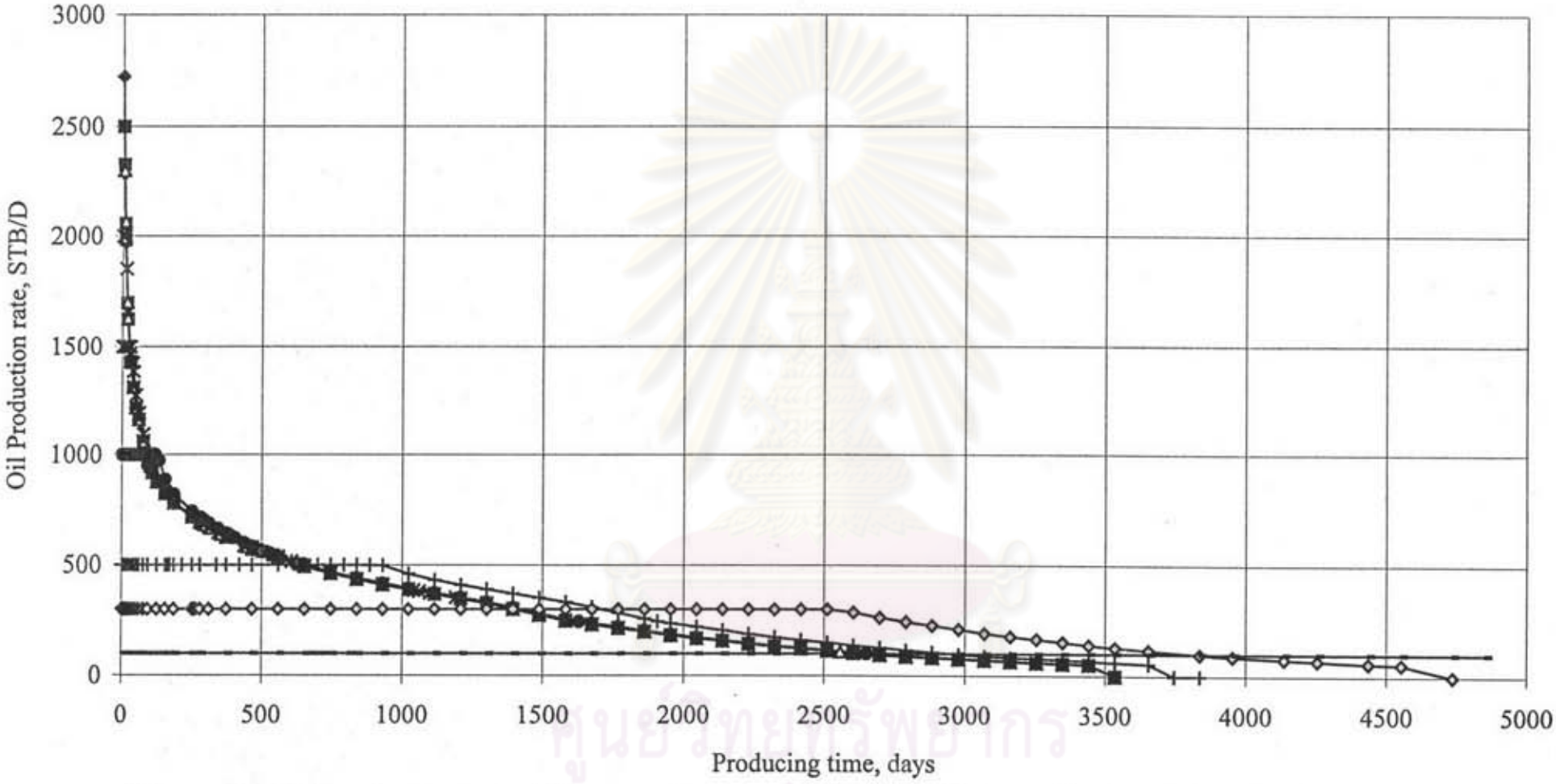

Figure 8.1 Oil production rate of the cases in the group having minimum flowing tubing head pressure of 50 psia

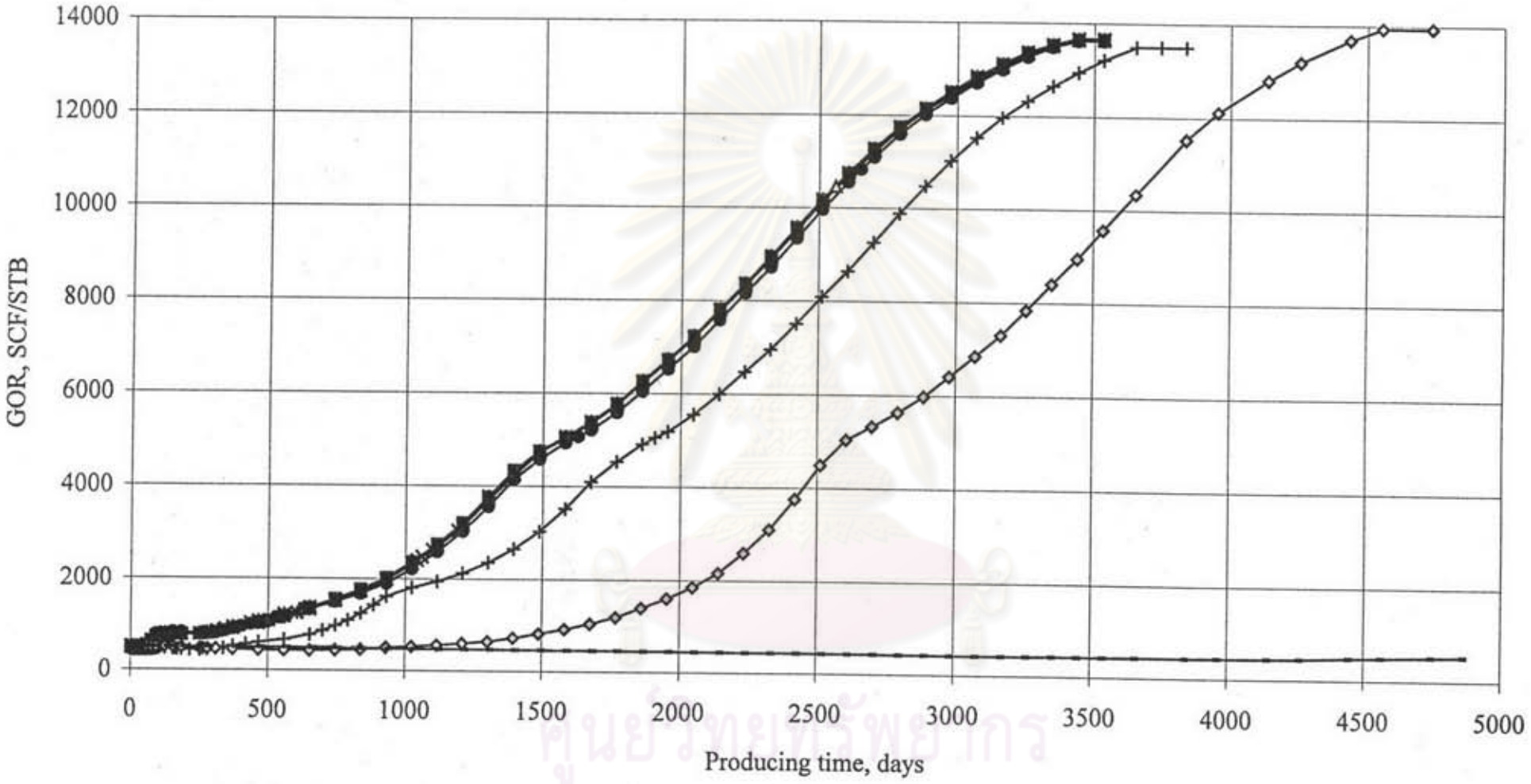

Figure 8.2 GOR of the cases in the group having minimum flowing tubing head pressure of 50 psia

Maximum allowable oil rate

Qo = 2725 STB/D, Qo = 2500 STB/D, Qo = 2300 STB/D, Qo = 2000 STB/D, Qo = 1500 STB/D, Qo = 1000 STB/D, Qo = 500 STB/D, Qo = 300 STB/D, Qo = 100 STB/D

Although oil production rate and GOR of the cases with maximum allowable oil rate of 1,000 STB/D or greater look similar, flowing tubing head pressure of each case in the group is different, as shown in Figure 8.3. The case with higher maximum allowable oil rate has rapid drop in flowing tubing head pressure than does the case with lower maximum allowable oil rate. For example, the case with maximum allowable oil rate of 2,725 STB/D has flowing tubing head pressure of 50 psia from the start of the production while the case with maximum allowable oil rate of 1,000 STB/D has to produce for 130 days prior to having flowing tubing head pressure of 50 psia. That is, the higher the maximum allowable oil production rate, the faster the flowing tubing head pressure drops. Most of the cases in this group, however, have reached flowing tubing head pressure of 50 psia within short time.

Close investigations of the flowing tubing head pressure are made. It is found that flowing tubing head pressure drops rapidly as the well starts to produce. The flowing tubing head pressure keep dropping at this rapid rate for a certain period prior to having slower dropping rate. During this slow dropping period, GOR plot (Figure 8.2) indicates that free gas forms in the reservoir but it is still immobile. Rate of tubing head pressure drop increases again as GOR becomes greater than initial gas oil ratio. Note that this phenomenon can be observed from the cases which the maximum allowable oil rates are not too high. Plots of those cases with very high maximum allowable oil rates do not illustrate this phenomenon since their flowing tubing head pressure become the minimum setting before the observation of GOR change can be made. In the 50-psia group, it is found that the rate of pressure change in the plots of flowing tubing head pressure of the cases with maximum allowable oil rates of 1,500 STB/D or greater changes gradually.

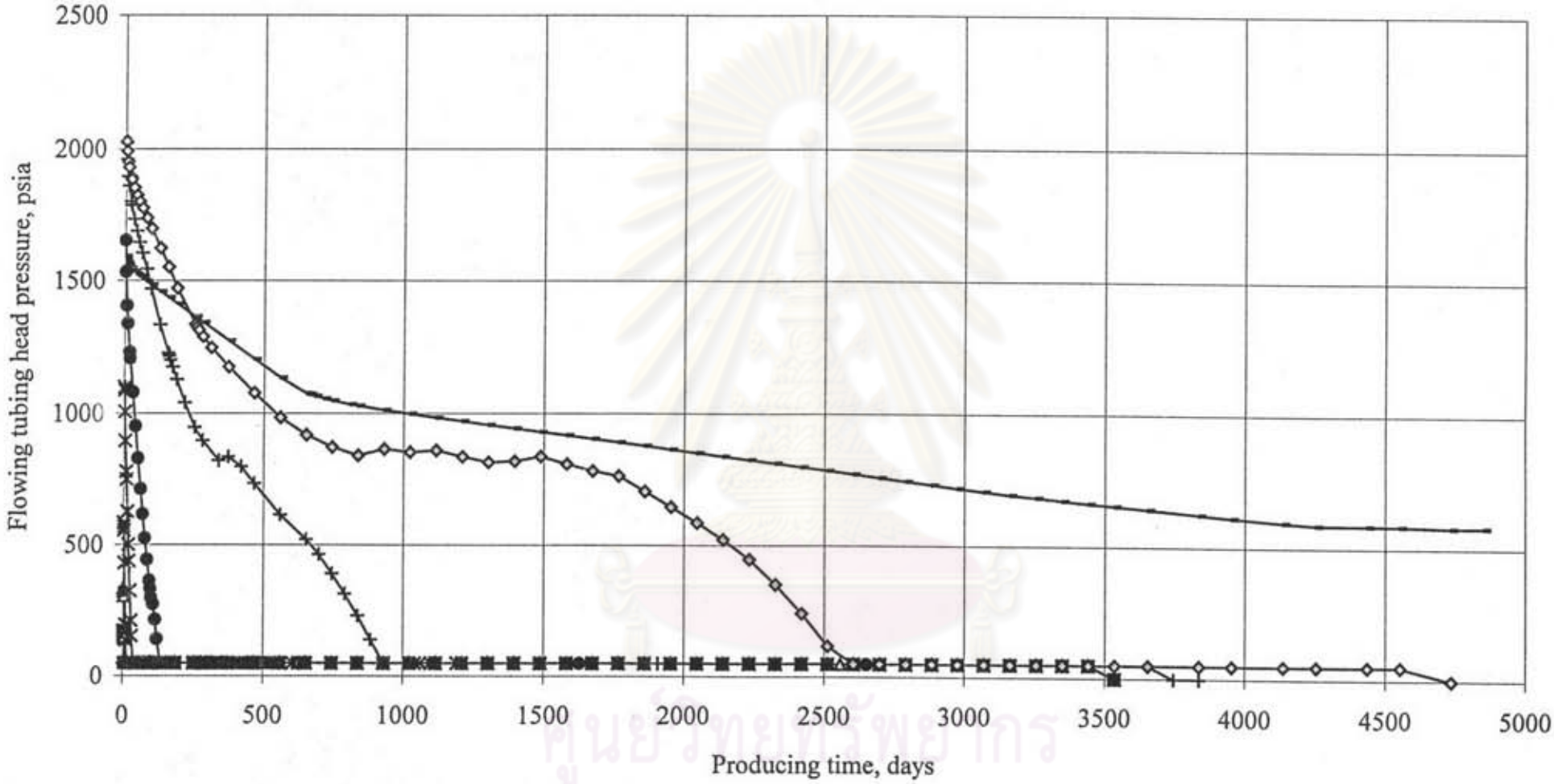

Figure 8.3 Flowing tubing head pressure of the cases in the group having minimum flowing tubing head pressure of 50 psia

Plots of oil recovery against producing time shown in Figure 8.4 illustrate that ultimate oil recovery at the abandonment of each case is approximately identical. Although the magnitude of ultimate recovery of oil are approximately equal, but time to reach that recovery of individual case is different. The magnitudes of ultimate oil recovery observed from these results vary between 10.49 to 10.57%. A close observation of time to reach ultimate oil recovery reveals that producing time prior to reaching ultimate oil recovery increases drastically between the cases which have maximum allowable oil rates of 500 STB/D and of 1,000 STB/D. The cases which have maximum allowable oil rate of 1,000 STB/D or greater have equal producing time to reach ultimate oil recovery of 3,441 days. In contrast, the well of the case with 500 STB/D has to produce for 3,653 days prior to reaching its ultimate oil recovery. In addition, oil recovery at various time points of the cases with maximum allowable oil rate of 1,000 STB/D or greater are also close.

From the above observations, it is considered that the conventional plots do not give significant identifier for using to improve time to reach ultimate oil recovery. Conventional plots of surface information include oil production rate, GOR, flowing tubing head pressure, and oil recovery fraction. These types of information are plotted against producing time. In addition, several plots of the surface information obtained from several maximum allowable oil rates have similar shapes. In these cases, additional plots to conventional plots are used for investigations. Additional plots are plots of derivative of oil flow rate with respect to producing time, derivative of tubing head pressure with respect to producing time, and derivative of GOR with respect to producing time. These derivatives are plotted against producing time. The derivative

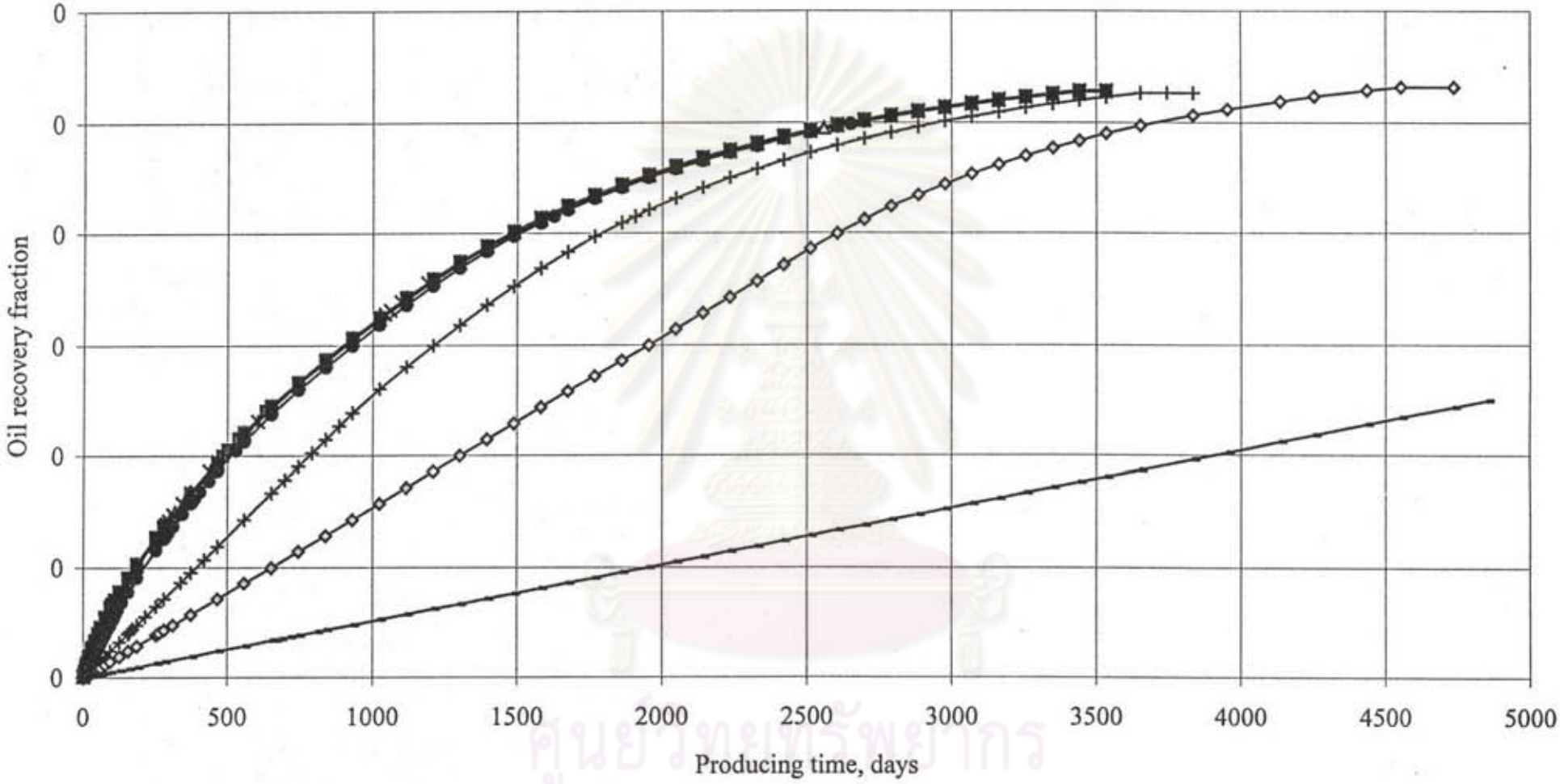

Figure 8.4 Oil recovery fraction of the cases in the group having minimum flowing tubing head pressure of 50 psia

plots include both first and second order derivatives. These derivative plots of surface information are considered as possible means which can be used as an identifier for improving oil recovery from the reservoir. The derivative is determined at one time lag, i.e., the derivative value at time n is determined from the values at time n and n-1. The derivative is plotted on the cartesian scale.

The first order derivative of oil production rate with respect to time plotted against producing time is primarily considered. This is because it is concluded from the previous three chapters that the maximum allowable oil production rates affect oil recovery at various time points. The curves of the plot of the first order derivative of oil production rates with respect to producing time against producing time have the negative values of the derivatives at early producing time and approach zero value of the derivative at later time, as shown in Figure 8.5. All the cases with different maximum allowable rates have similar curves. It is difficult to notice the difference between each curve. Therefore, this type of plot can not be used for this purpose.

Figure 8.6 is a plot of the second order derivative of oil production rate with respect to time against producing time. It is seen in this plot that the second order derivative of oil production rate with respect to time plotted against producing time do not show significant shape which can probably be used for the purpose of this investigation. Therefore, it will not be considered further.

Another type of the derivative plot is the first order of derivative of GOR with respect to producing time. This derivative is plotted against producing time, as shown in Figure 8.7. The shape of the derivative plot obtained from each case is similar to that of other cases. However, the duration of each portion of the curve to reach specific shape or character is different. The curves of derivative of GOR for the cases with maximum allowable oil rates of 1,000 STB/D or greater reach a specific shape at

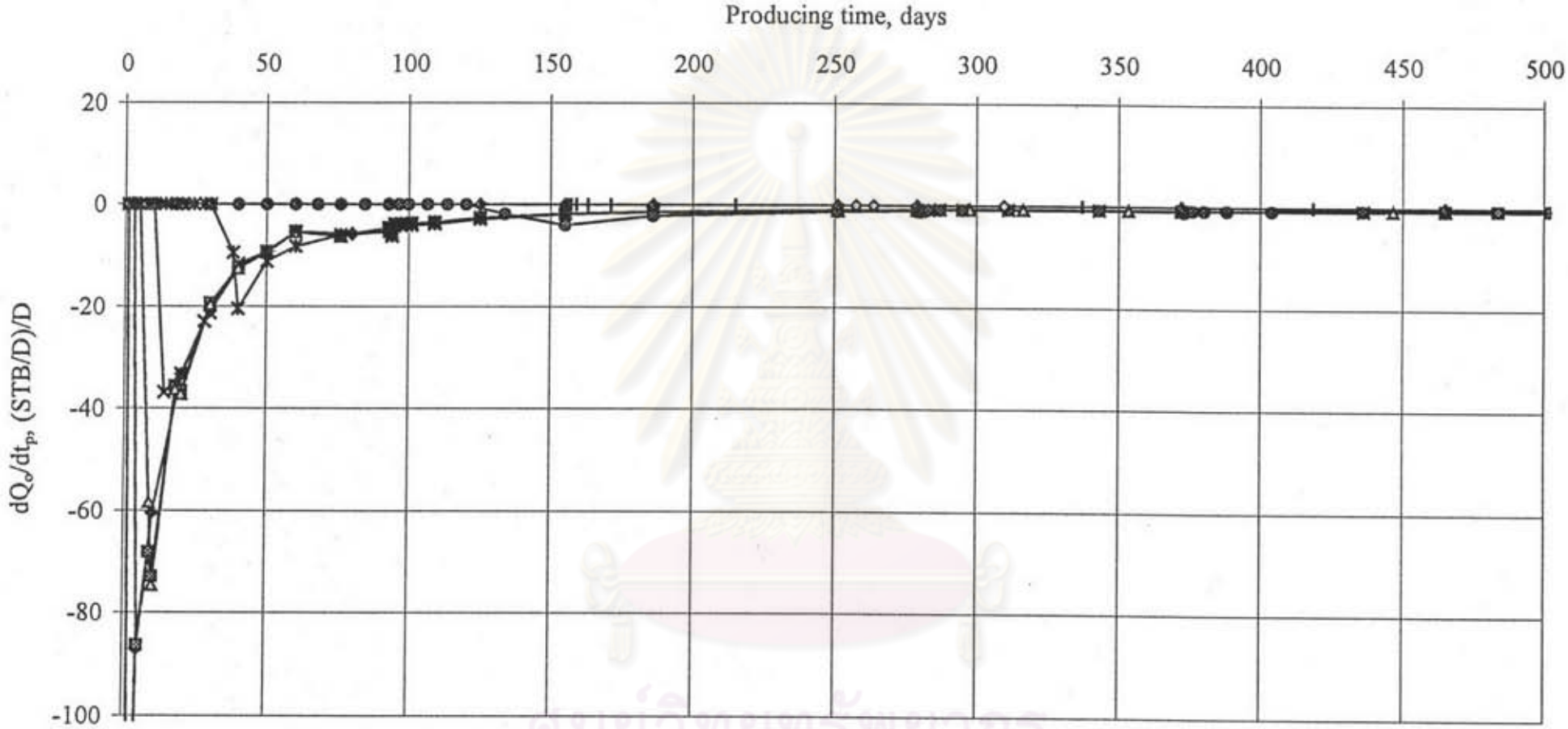

Figure 8.5 The first order derivative of oil rate with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

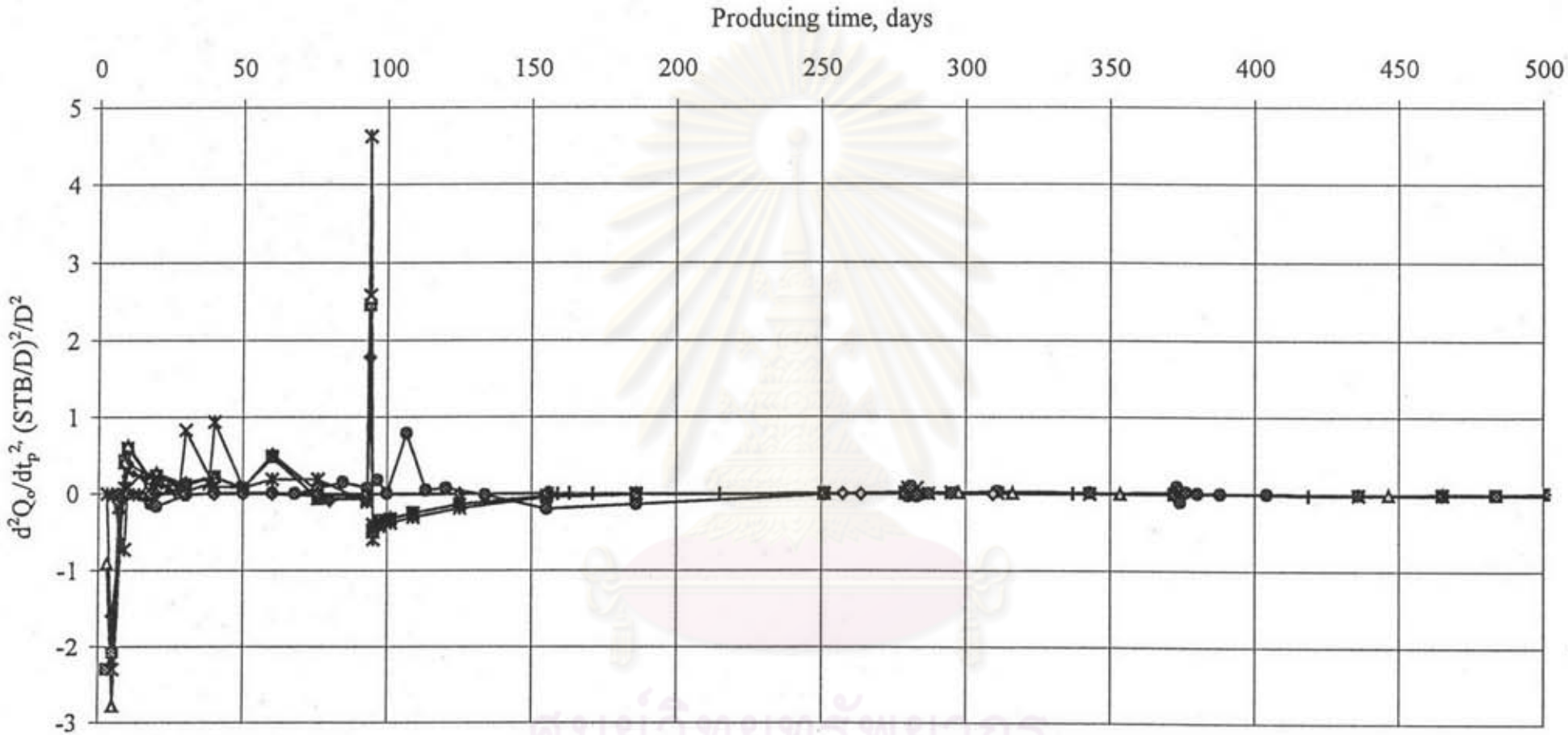

Figure 8.6 The second order derivative of oil rate with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

Maximum allowable oil rate

Qo = 2725 STB/D, Qo = 2500 STB/D, Qo = 2300 STB/D, Qo = 2000 STB/D, Qo = 1500 STB/D, Qo = 1000 STB/D, Qo = 500 STB/D, Qo = 300 STB/D, Qo = 100 STB/D

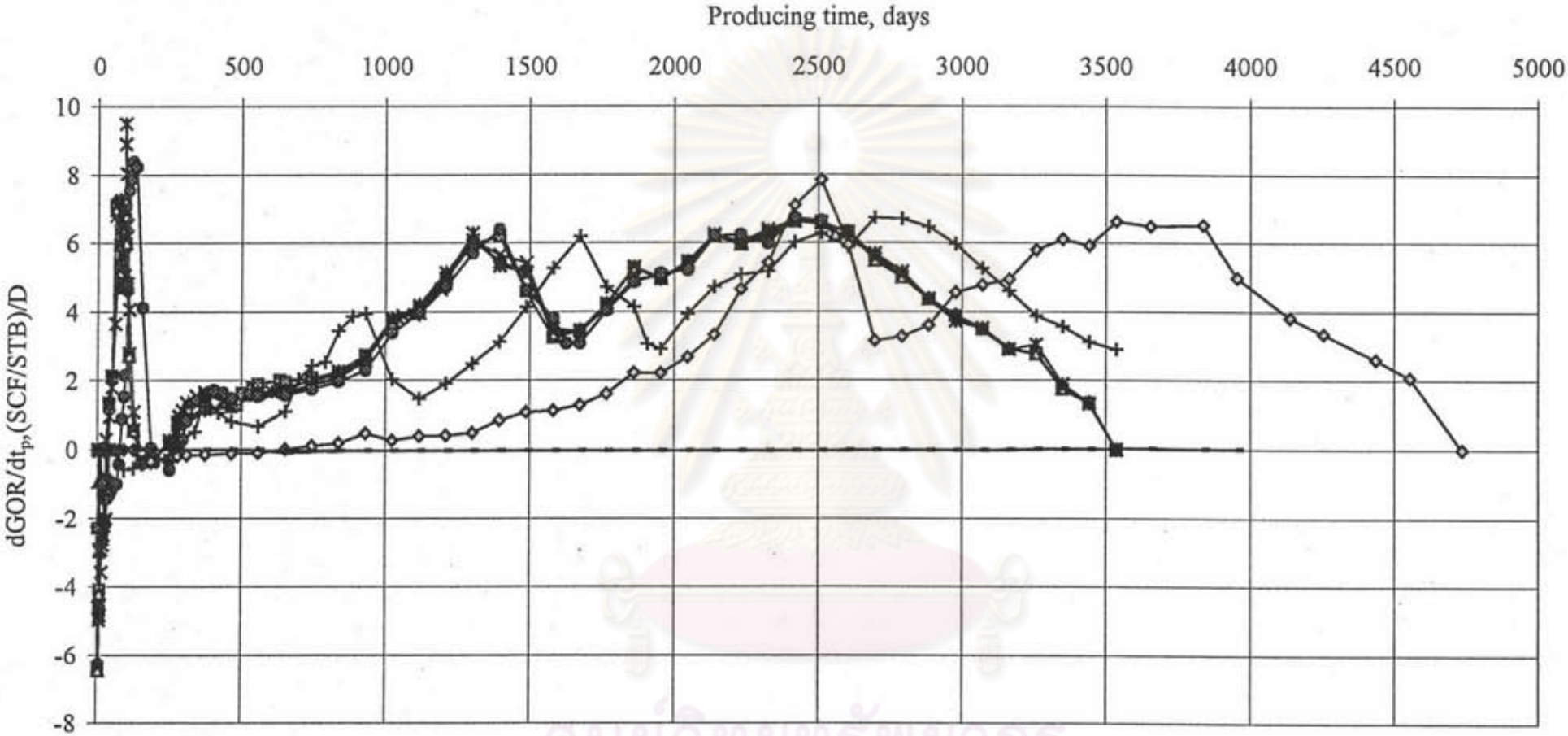

Figure 8.7 The first order derivative of GOR with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

earlier time than those of the cases with the maximum allowable oil rate of 500 STB/D or less. In addition, the lower the maximum allowable oil rate, the later the portion of the specific shape is reached. The investigations of derivative plots are extended to cover the second order derivative of GOR with respect to producing time. However, the shape of the second order derivative of GOR plotted against producing time is scatter, as shown in Figure 8.8. No remarkable trend can be made from this plot.

The other surface information which can probably be used for improving oil recovery is the first order derivative of flowing tubing head pressure with respect to producing time. Figure 8.9 is the plot of the first order derivative of flowing tubing head pressure against producing time. It is found from this figure that the shape of each line obtained from each case is similar. Each curve starts from the negative value and reaches zero as the well has produced for a certain number of days. However, the first order derivatives of flowing tubing head pressure curves can be divided into three groups. The group which has high maximum allowable oil rate has the derivative which approaches zero value in very short time. This can be seen from the curves of the cases having maximum allowable rates of 1,500 STB/D and greater. The second group has the derivative curve which approaches zero value in relatively longer than that of the first group. The curve of the case with maximum allowable oil rate of 1,000 STB/D has this behavior. The derivative of the last group increase gently and approaches zero later than that of the second group. The derivatives of flowing tubing head pressure of the cases with maximum allowable oil rates of 500 STB/D and lower are in this group.

Another notification can be made from the plot of the first order derivative of flowing tubing head pressure with respect to producing time. If the well has produced

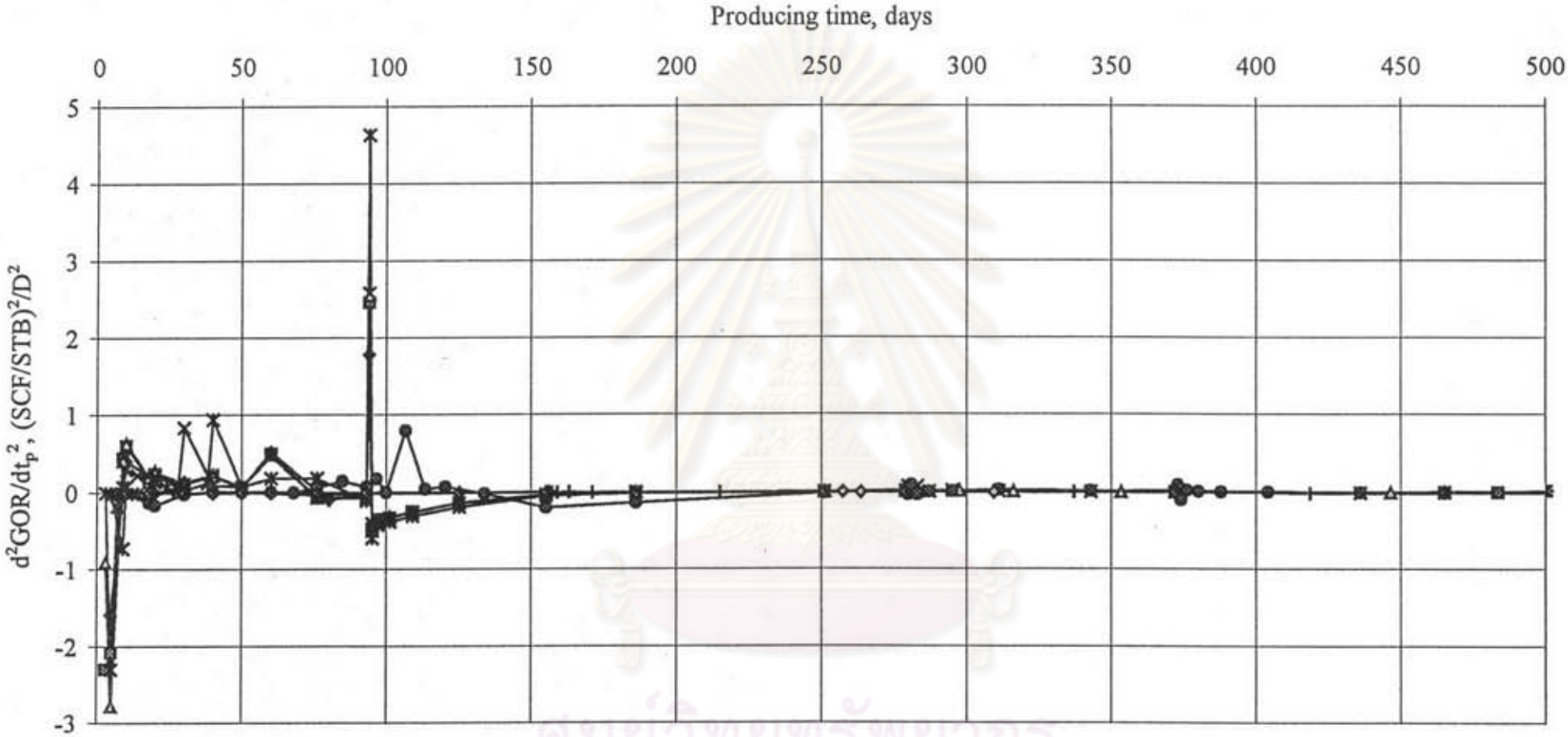

Figure 8.8 The second order derivative of GOR with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

Maximum allowable oil rate

Qo = 2725 STB/D, Qo = 2500 STB/D, Qo = 2300 STB/D, Qo = 2000 STB/D, Qo = 1500 STB/D, Qo = 1000 STB/D, Qo = 500 STB/D, Qo = 300 STB/D, Qo = 100 STB/D

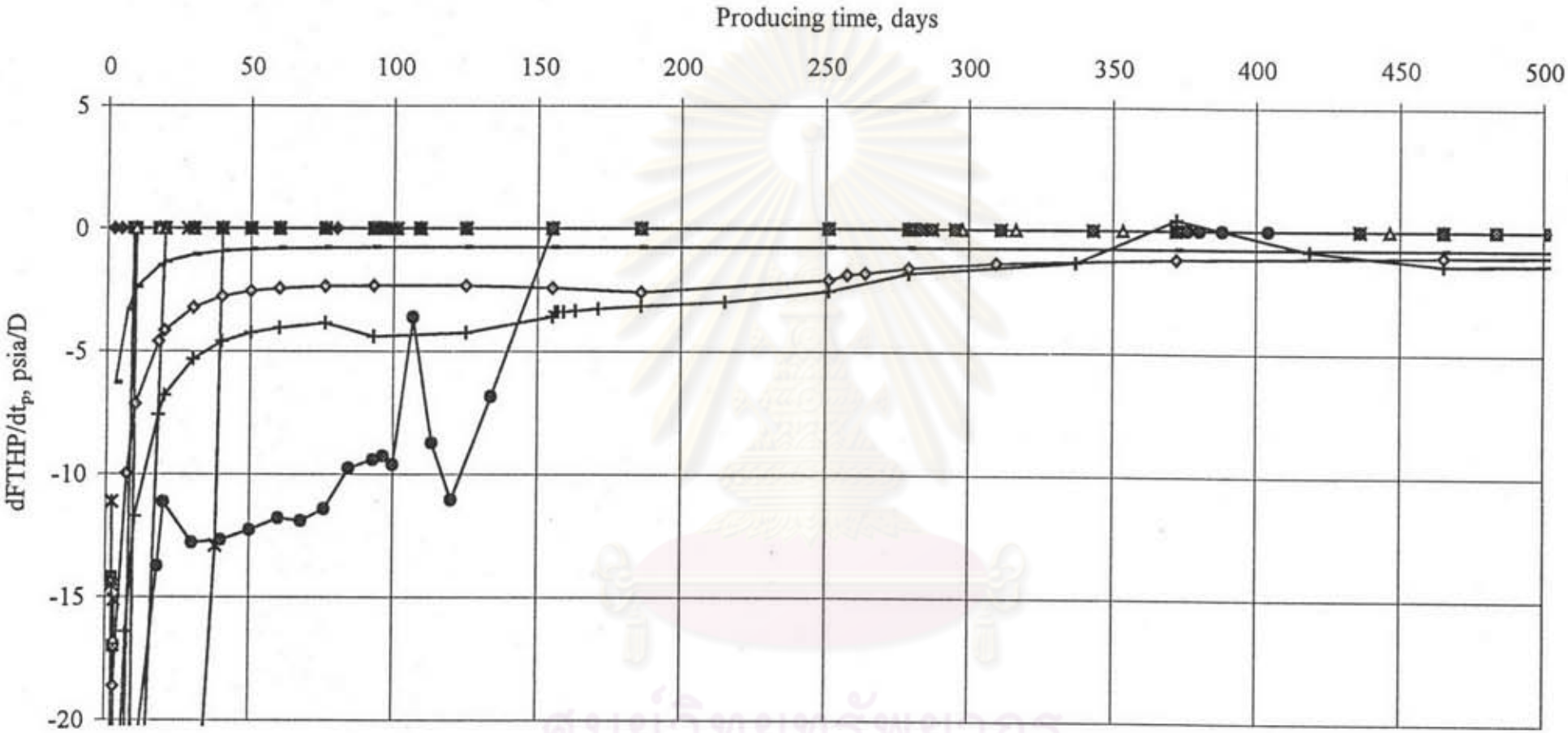

Figure 8.9 The first order derivative of flowing tubing head presssure with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

Maximum allowable oil rate

Qo = 2725 STB/D Qo = 2500 STB/D Qo = 2300 STB/D Qo = 2000 STB/D Qo = 1500 STB/D Qo = 1000 STB/D
Qo = 500 STB/D Qo = 300 STB/D Qo = 100 STB/D

long enough to have GOR greater than R_{si} while its flowing tubing head pressure is still greater than minimum value, an abrupt increase of the derivative of flowing tubing head pressure can be observed. This abrupt increase of the derivative is found at the point where GOR becomes greater than R_{si}. However, if the well is allowed to produce at very high maximum allowable oil rate, the abrupt increase of the derivative of flowing tubing head pressure when GOR just becomes greater than R_{si} is not present.

The second order derivative of flowing tubing head pressure with respect to time, shown in Figure 8.10, reveals that the shape of the second derivative of flowing tubing head pressure are not unique. Thus the plots of the second derivative will not be considered further.

The results from the simulation of the second group which the minimum flowing tubing head pressure is set to 100 psia are similar to those of the first group with 50 psia minimum flowing tubing head pressure. The behavior of oil production rates is similar to that of the 50-psia group. Figure 8.11 shows oil production rates within the first 300 days of production while Figure 8.12 shows oil production rates up to the abandonment of the natural depletion process.

GOR behavior of the cases in this group during the first 300 days of production is shown in Figure 8.13. Figure 8.14 is a comparison of GOR until the end of natural depletion process among each case in this group. The behavior of GOR of all cases using 100 psia as minimum flowing tubing head pressure are similar to typical GOR behavior of a solution gas drive reservoir. This observation is similar to that of the first group.

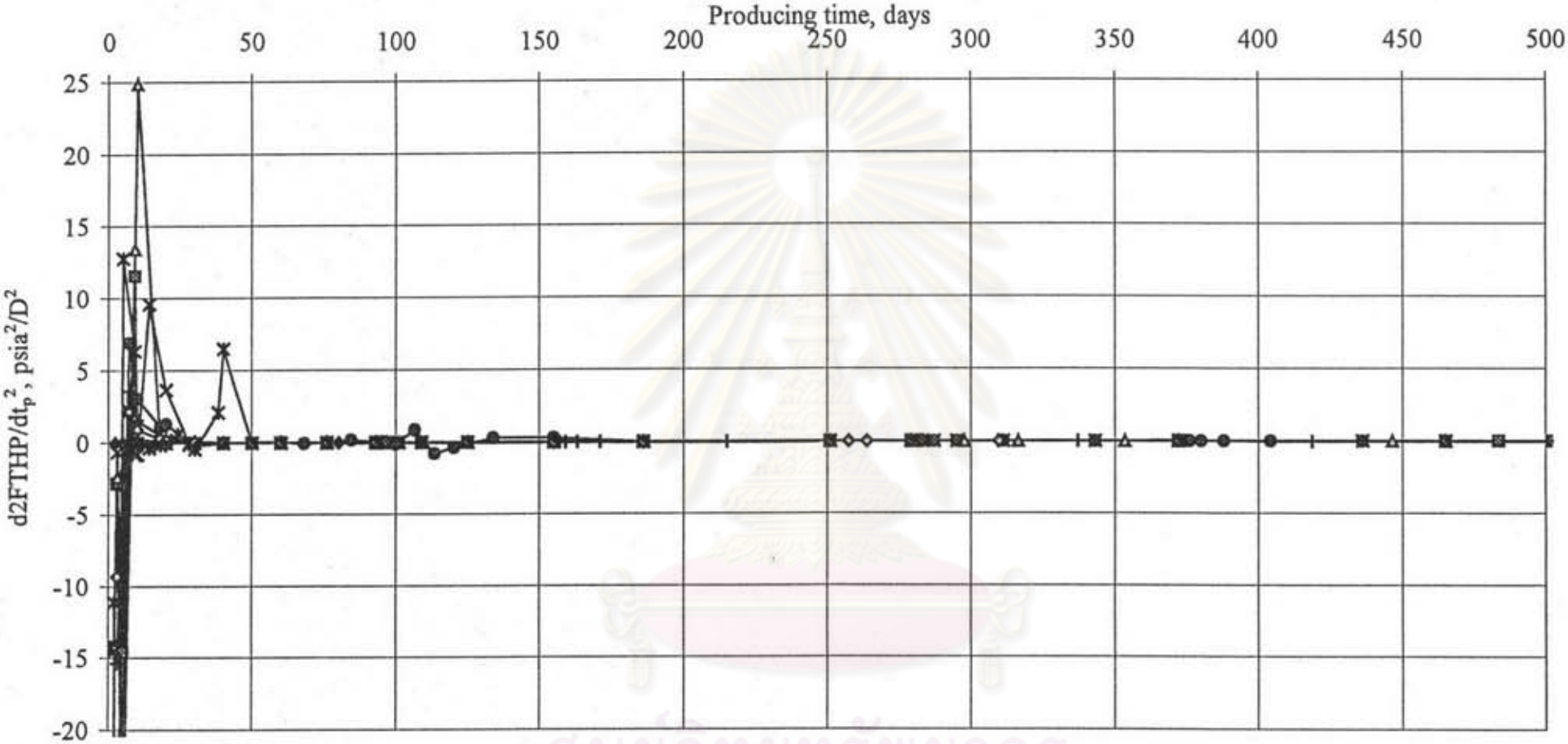

Figure 8.10 The second order derivative of flowing tubing head pressure with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

Maximum allowable oil rate

Qo = 2725 STB/D, Qo = 2500 STB/D, Qo = 2300 STB/D, Qo = 2000 STB/D, Qo = 1500 STB/D, Qo = 1000 STB/D, Qo = 500 STB/D, Qo = 300 STB/D, Qo = 100 STB/D

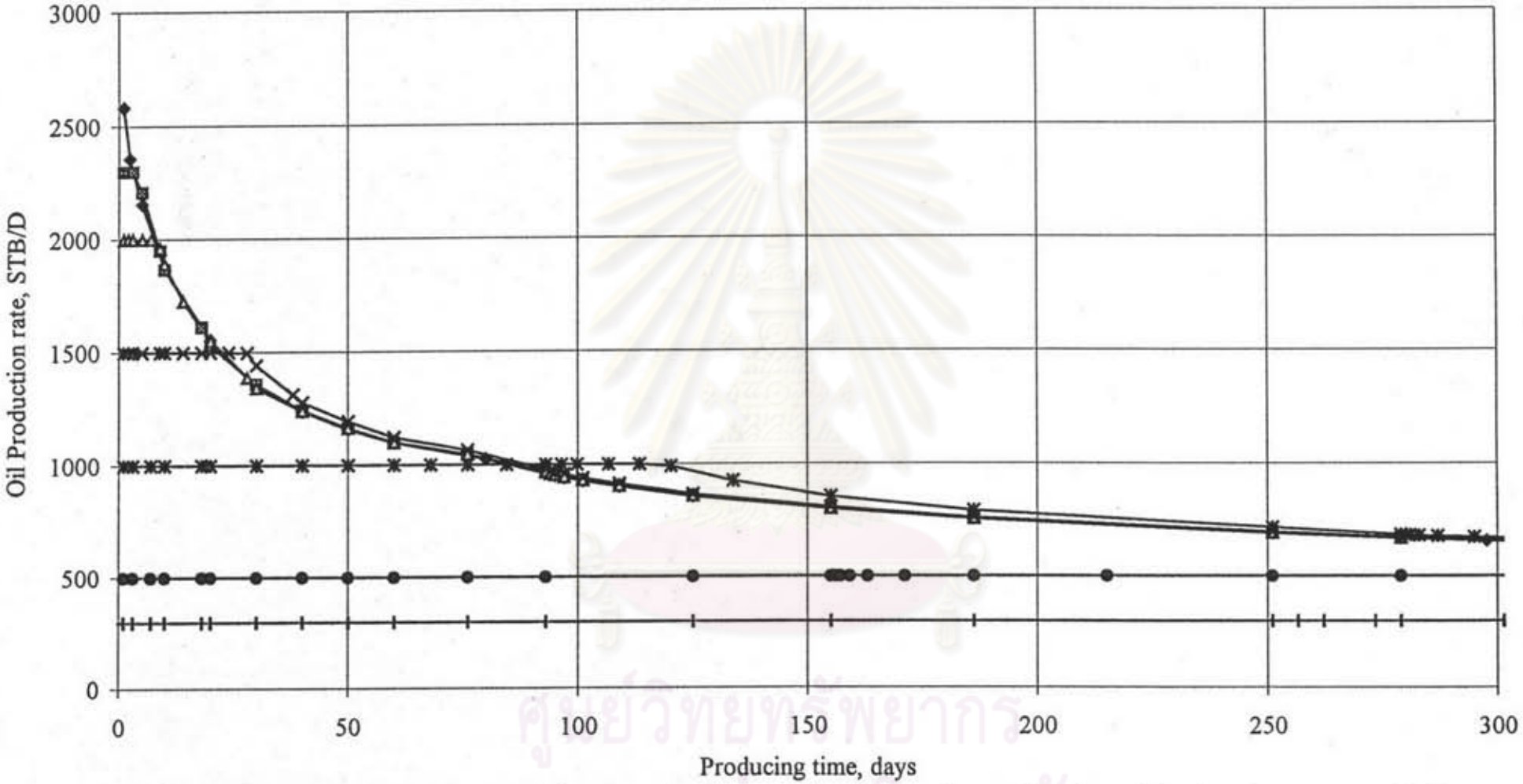

Figure 8.11 Oil production rate of the cases in the group having minimum flowing tubing head pressure of 100 psia during the first 300 days

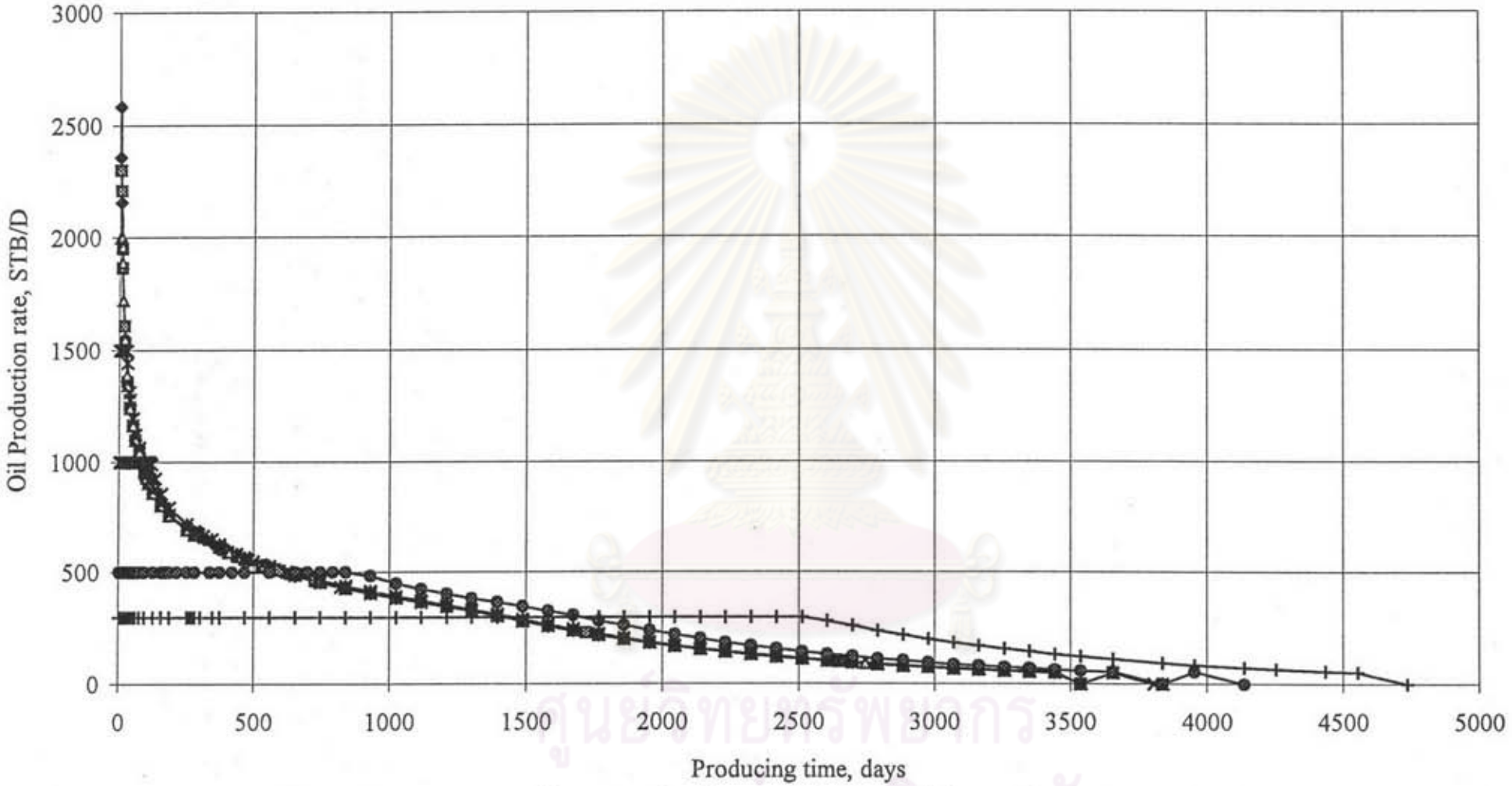

Figure 8.12 Oil production rate of the cases in the group having minimum flowing tubing head pressure of 100 psia

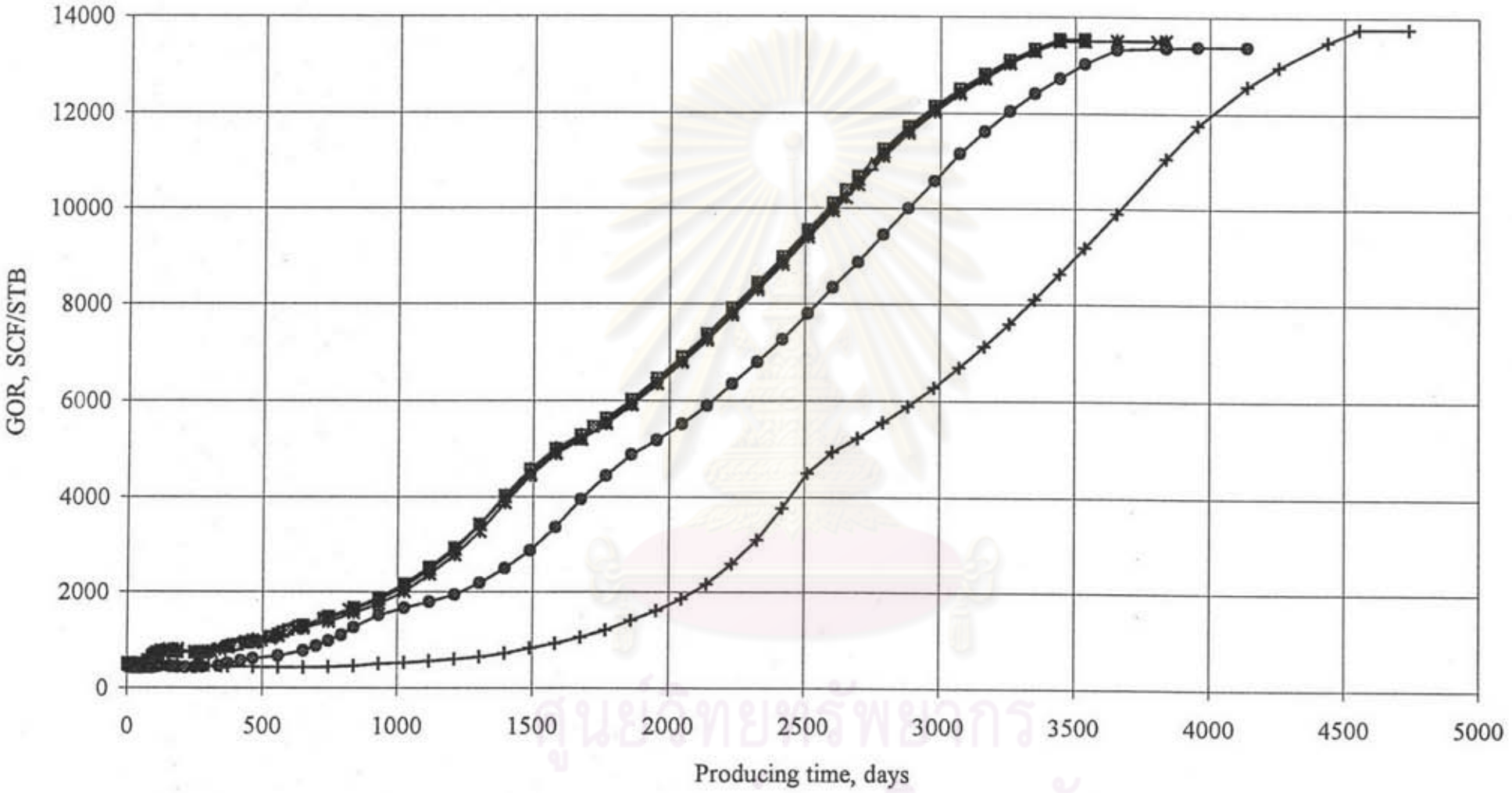

Figure 8.13 GOR of the cases in the group having minimum flowing tubing head pressure of 100 psia during the first 300 days

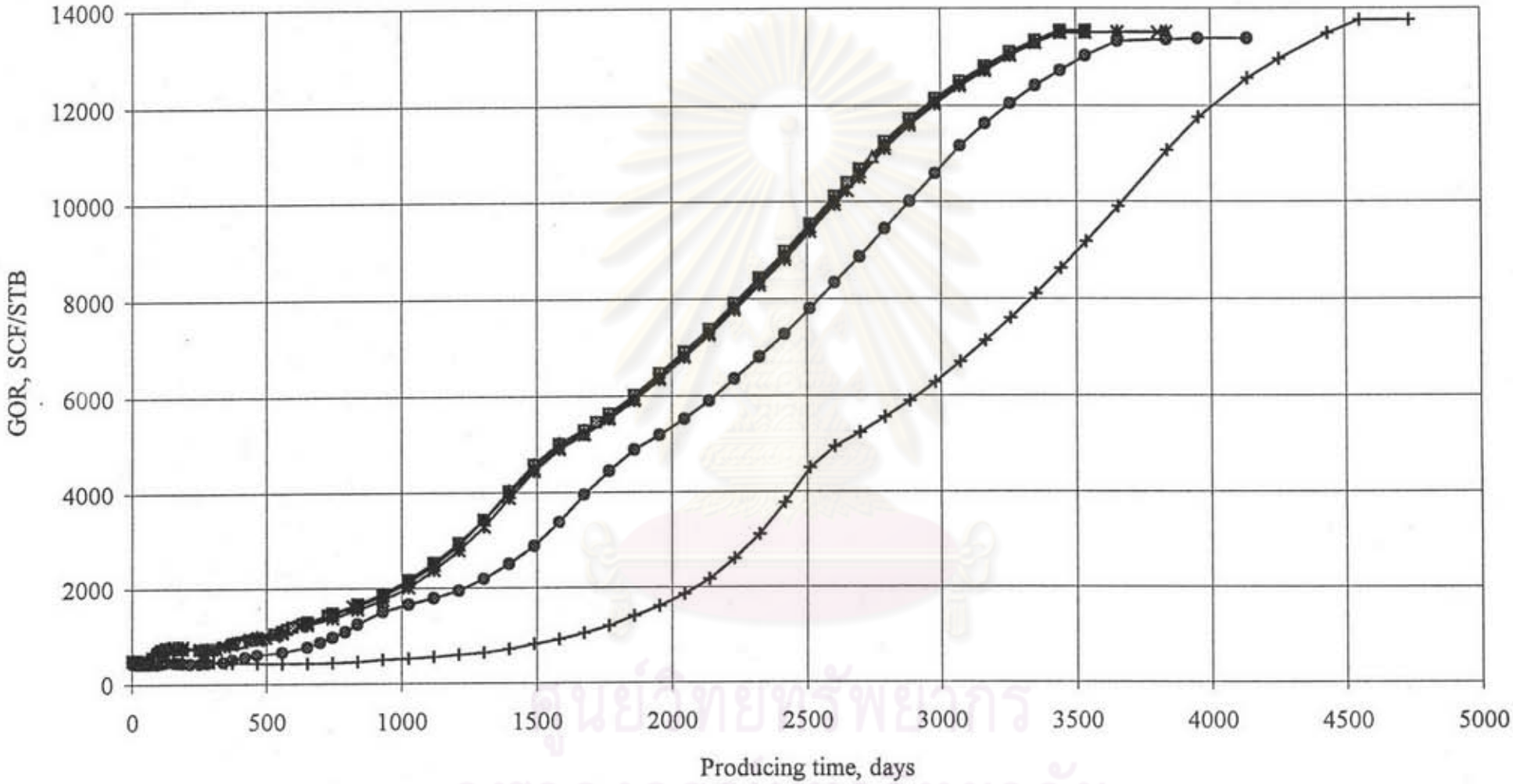

Figure 8.14 GOR of the cases in the group having minimum flowing tubing head pressure of 100 psia

Maximum allowable oil rate

Qo = 2584 STB/D Qo = 2300 STB/D Qo = 2000 STB/D Qo = 1500 STB/D Qo = 1000 STB/D Qo = 500 STB/D Qo = 300 STB/D

Figure 8.15 is a comparison of flowing tubing head pressure of each case in this group. The shape of flowing tubing head pressure of each case in this group is similar to that observed from the first group which minimum flowing tubing head pressure is set to 50 psia. The higher the maximum allowable oil rate, the faster the flowing tubing head pressure drops.

Plot of oil recovery obtained from each case in this 100 psia minimum flowing tubing head pressure is shown in Figure 8.16. This plot is similar to that of the first group. The cases with maximum allowable oil rate of 1,000 STB/D or greater have similar recovery fraction at all producing time. At early life of the reservoir, the case with 500 STB/D and 300 STB/D have lower oil recovery compared to those of the cases with 1,000 STB/D or greater. However, ultimate oil recovery of all cases are approximately equal although the cases with maximum allowable oil rates lower than 1,000 STB/D have longer producing time prior to reaching abandonment.

Figure 8.17 represents the plot of derivatives of oil production rates with respect to producing time against producing time of the cases with minimum flowing tubing head pressure of 100 psia. This plot is similar to that of the group with minimum flowing tubing head pressure of 50 psia. Thus this plot can not be used as an indicator for improving time for reaching ultimate recovery. The second order derivatives of oil rates plotted against producing time, shown in Figure 8.18, also show non unique behavior.

The plot of the first order derivatives of GOR with respect to producing time against producing time are shown in Figure 8.19. For the cases with maximum allowable oil rates of 1,000 STB/D or greater, time to reach specific shape of each curve is similar. Although the cases with maximum allowable oil rates of 500 and 300

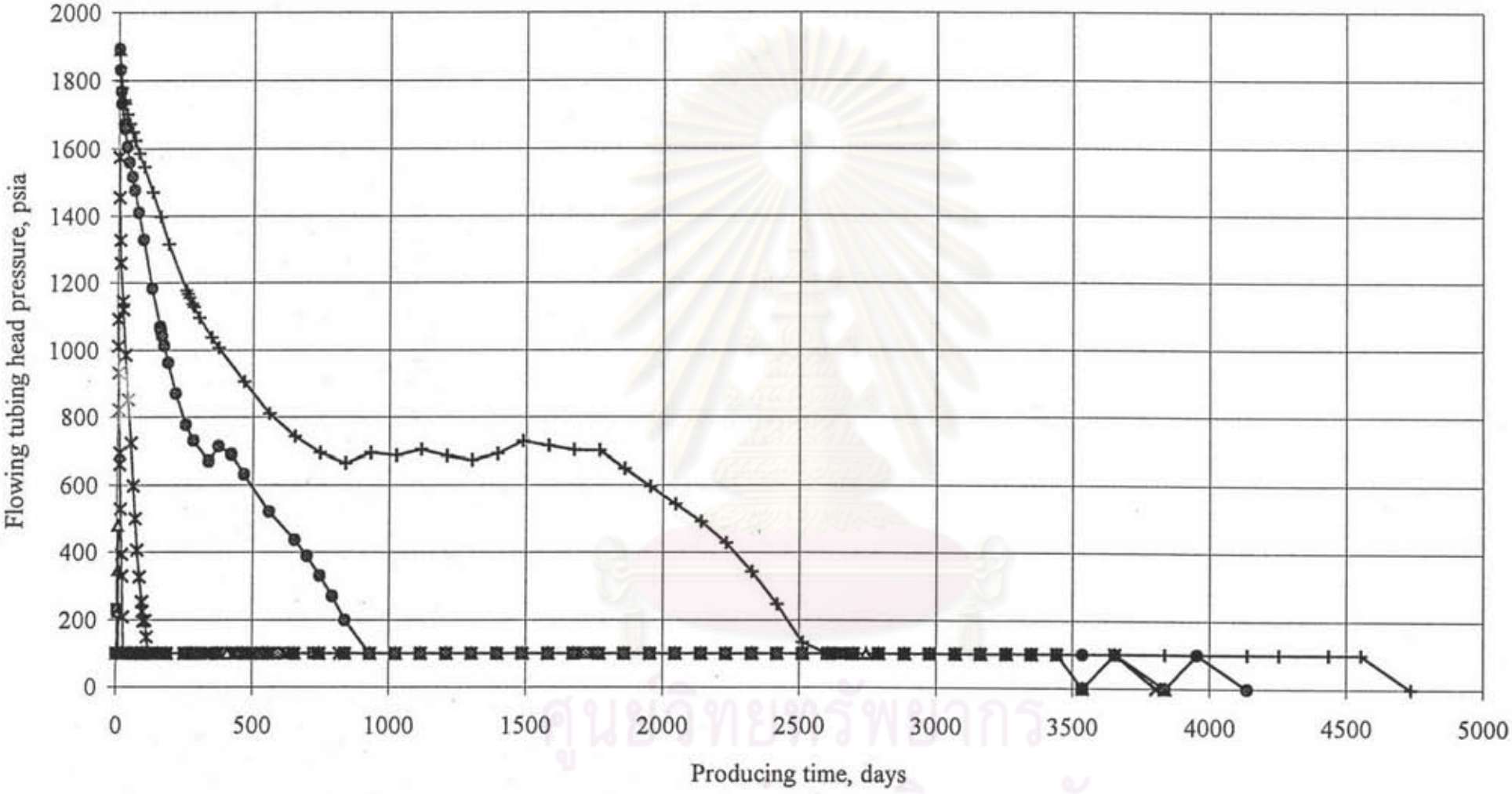

Figure 8.15 Flowing tubing head pressure of the cases in the group having minimum flowing tubing head pressure of 100 psia

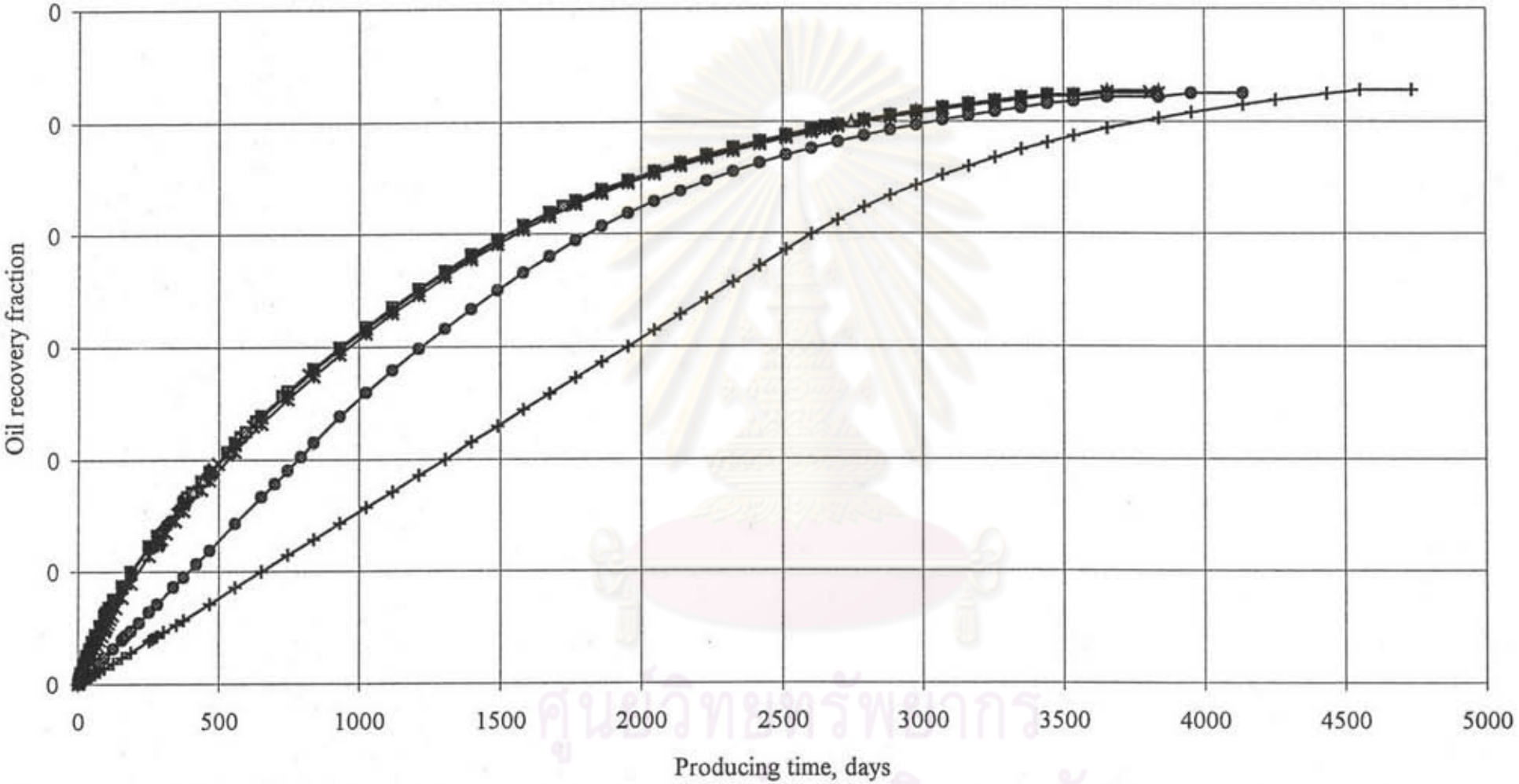

Figure 8.16 Comparison of oil recovery fraction of the case in the group of having minimum flowing tubing head pressure of 100 psia

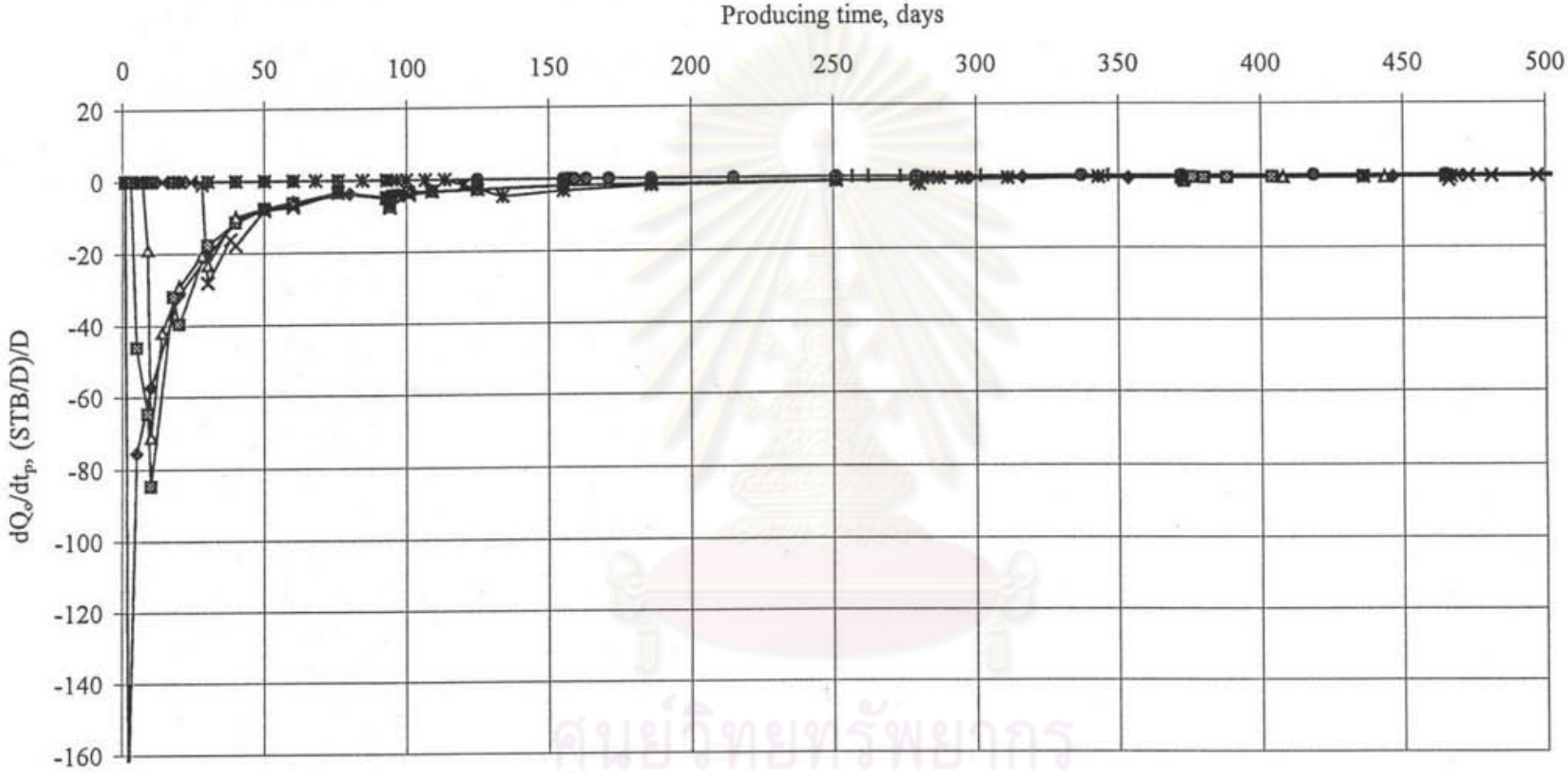

Figure 8.17 The first order derivative of oil rate with respect to time of the cases in the group having minimum flowing tubing head pressure of 100 psia

STB/D have longer time to reach those specific shape, the curves of these two cases are similar to that of the cases with maximum allowable oil rates of 1,000 STB/D and greater. Since the shape of each case is similar, the first order derivative of GOR with respect to producing time plotted against producing time can not be used as a tool for improving time to reach ultimate oil recovery. The second order derivative of GOR with respect to time are plotted against producing time, as shown in Figure 8.20. The shapes of these curves are not unique either. The curve of each case has its own shape. And this type of plotted will not be further used for improving time to reach ultimate recovery.

Figure 8.21 is the plot of the first order derivative of flowing tubing head pressure with respect to producing time plotted against producing time. This figure is similar to Figure 8.9. The curves in this figure can be divided into three groups. The cases with high maximum allowable oil rates have the derivatives which approach zero value within very short time. The case with maximum allowable oil rate of 1,000 STB/D has the curve which have a abrupt increase due to the increasing of GOR. The cases with maximum allowable oil rates of 500 and 300 STB/D have the curves which approach zero value at very long time compared to that of the other cases.

Figure 8.22 is a comparison of the second order derivatives of flowing tubing head pressure with respect to producing time against producing time. It can be seen from this figure that the shapes of the curves are not persuasive thus this plot is again not used further for this purpose.

The investigations made from the first two groups having different minimum flowing tubing head pressures reveal that the shape of the plots of surface information

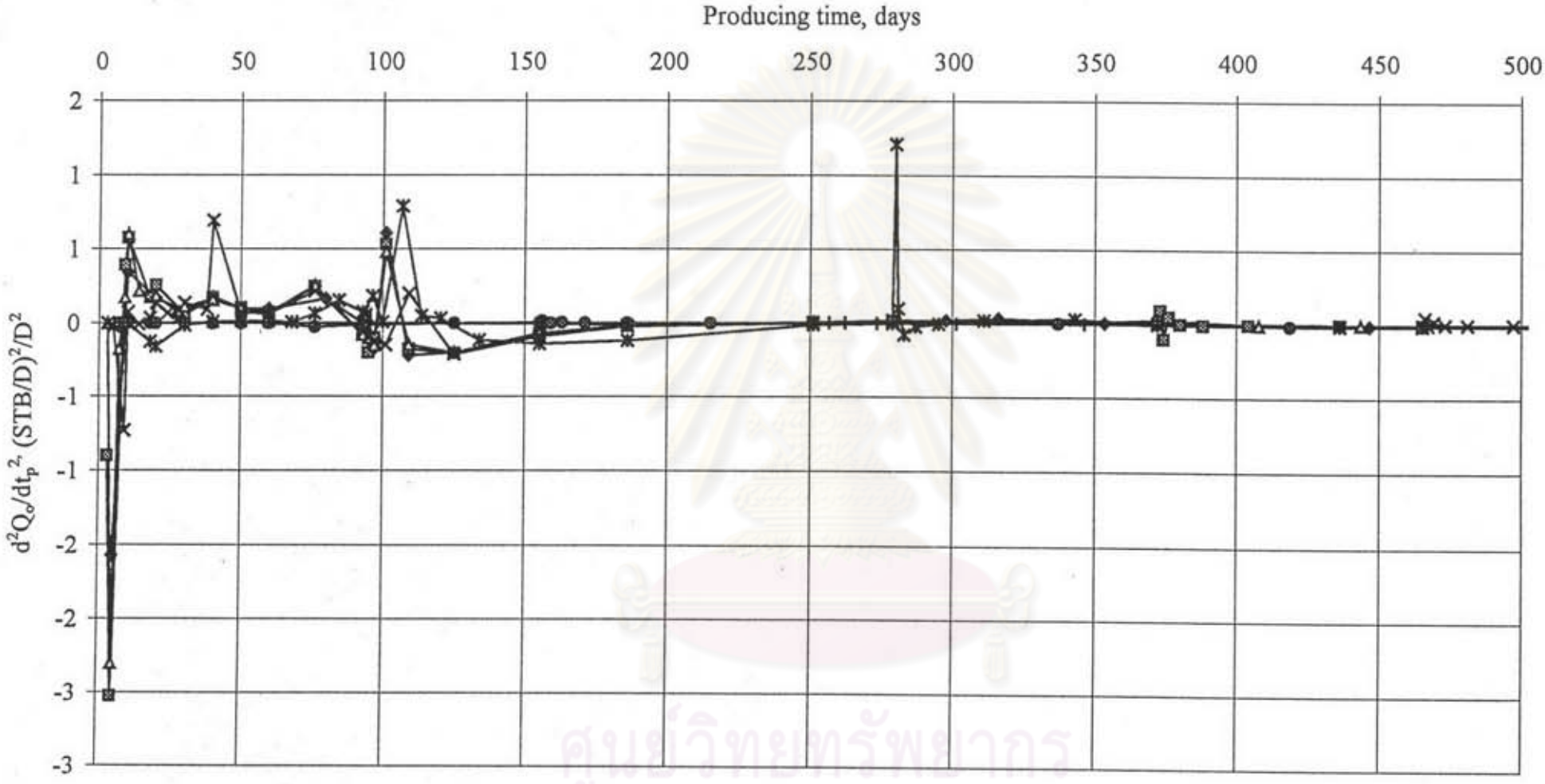

Figure 8.18 The second order derivative of oil rate with respect to time of the cases in the group having minimum flowing tubing head pressure of 100 psia

Maximum allowable oil rate

Qo = 2584 STB/D Qo = 2300 STB/D Qo = 2000 STB/D Qo = 1500 STB/D Qo = 1000 STB/D Qo = 500 STB/D Qo = 300 STB/D

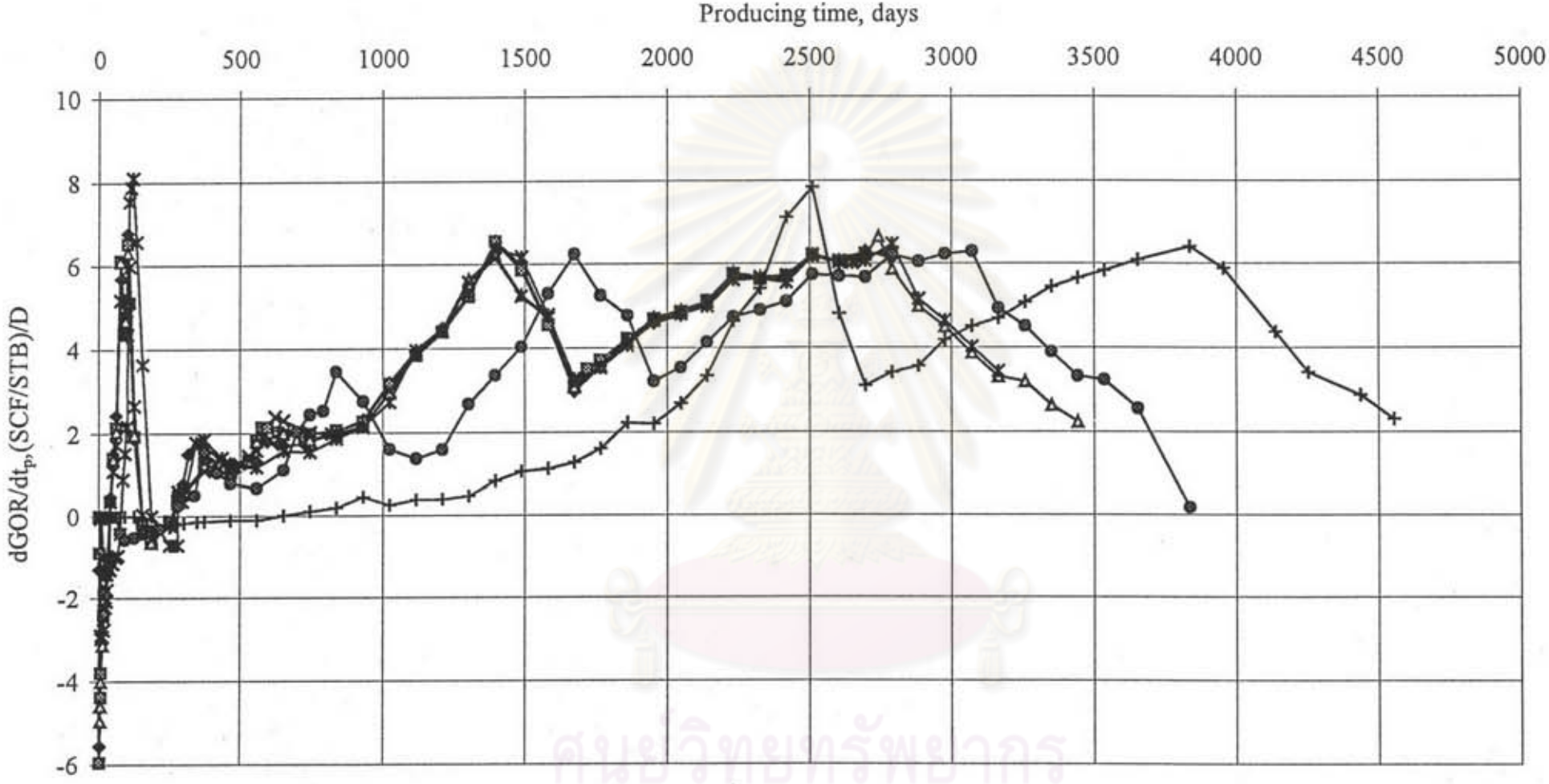

Figure 8.19 The first order derivative of GOR with respect to time of the cases in the group having minimum flowing tubing head pressure of 100 psia

Maximum allowable oil rate

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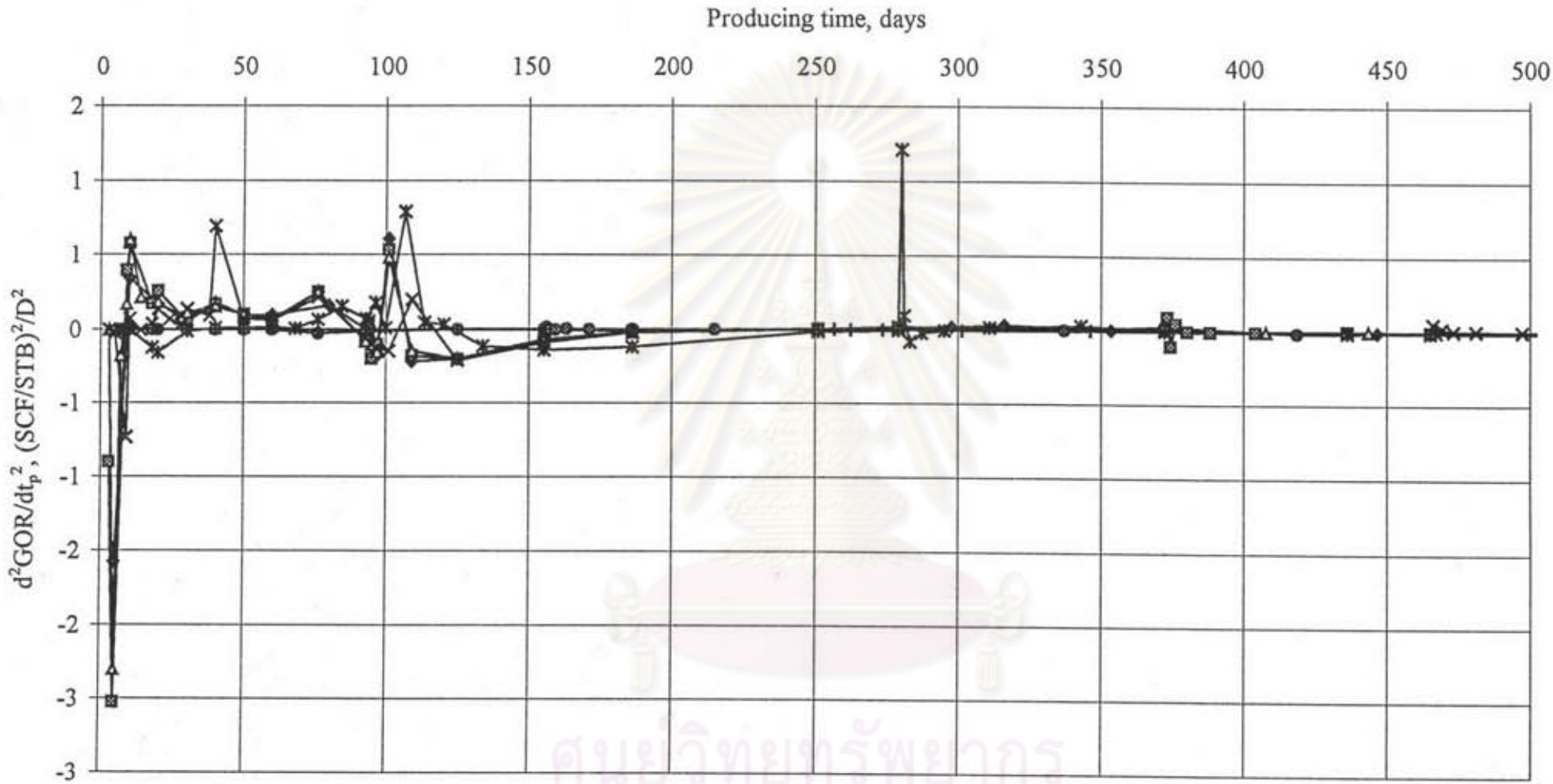

Figure 8.20 The second order derivative of GOR with respect to time of the cases in the group having minimum flowing tubing head pressure of 100 psia

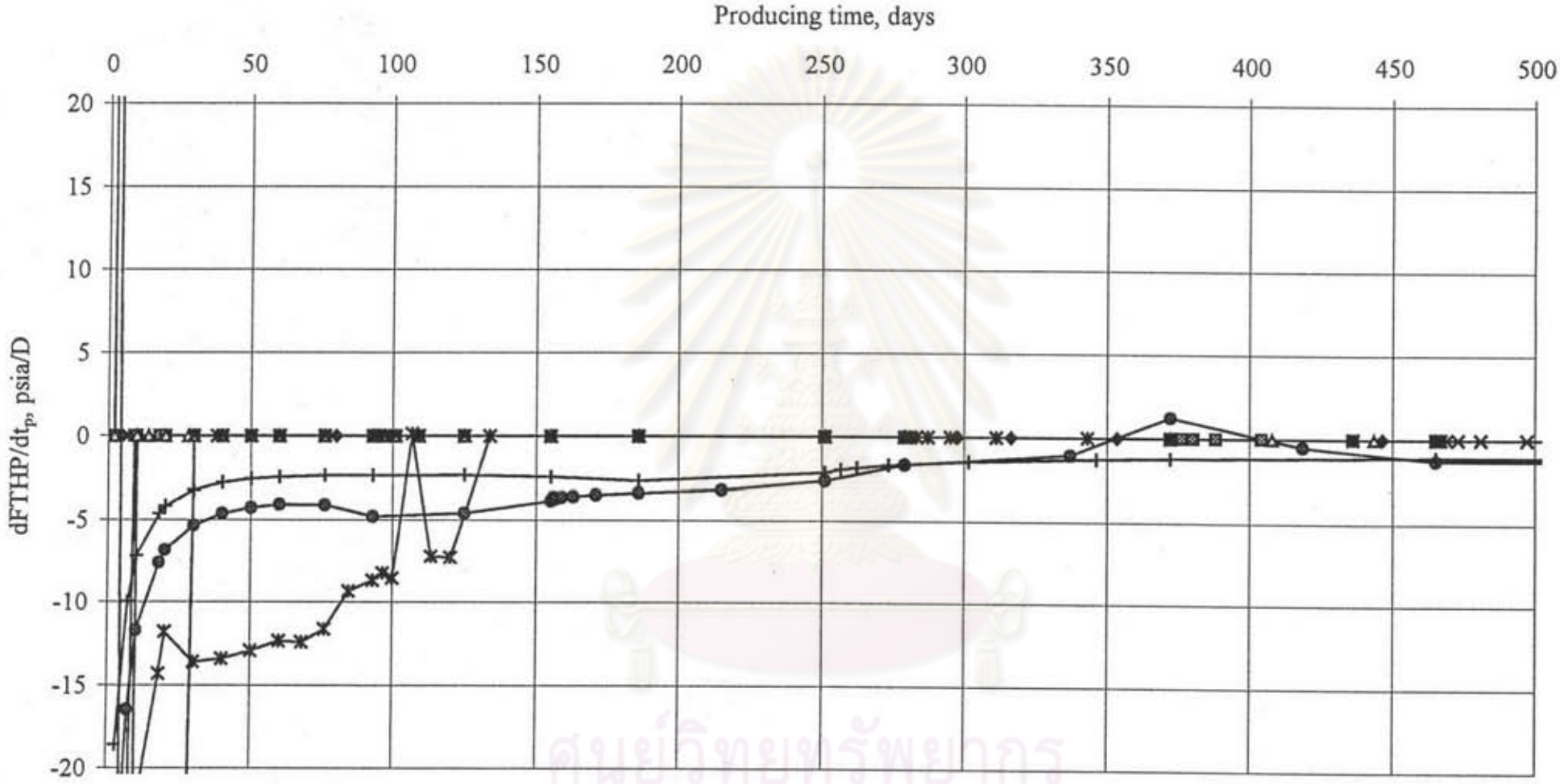

Figure 8.21 The first order derivative of flowing tubing head presssure with respect to time of the cases in the group having minimum flowing tubing head pressure of 100 psia

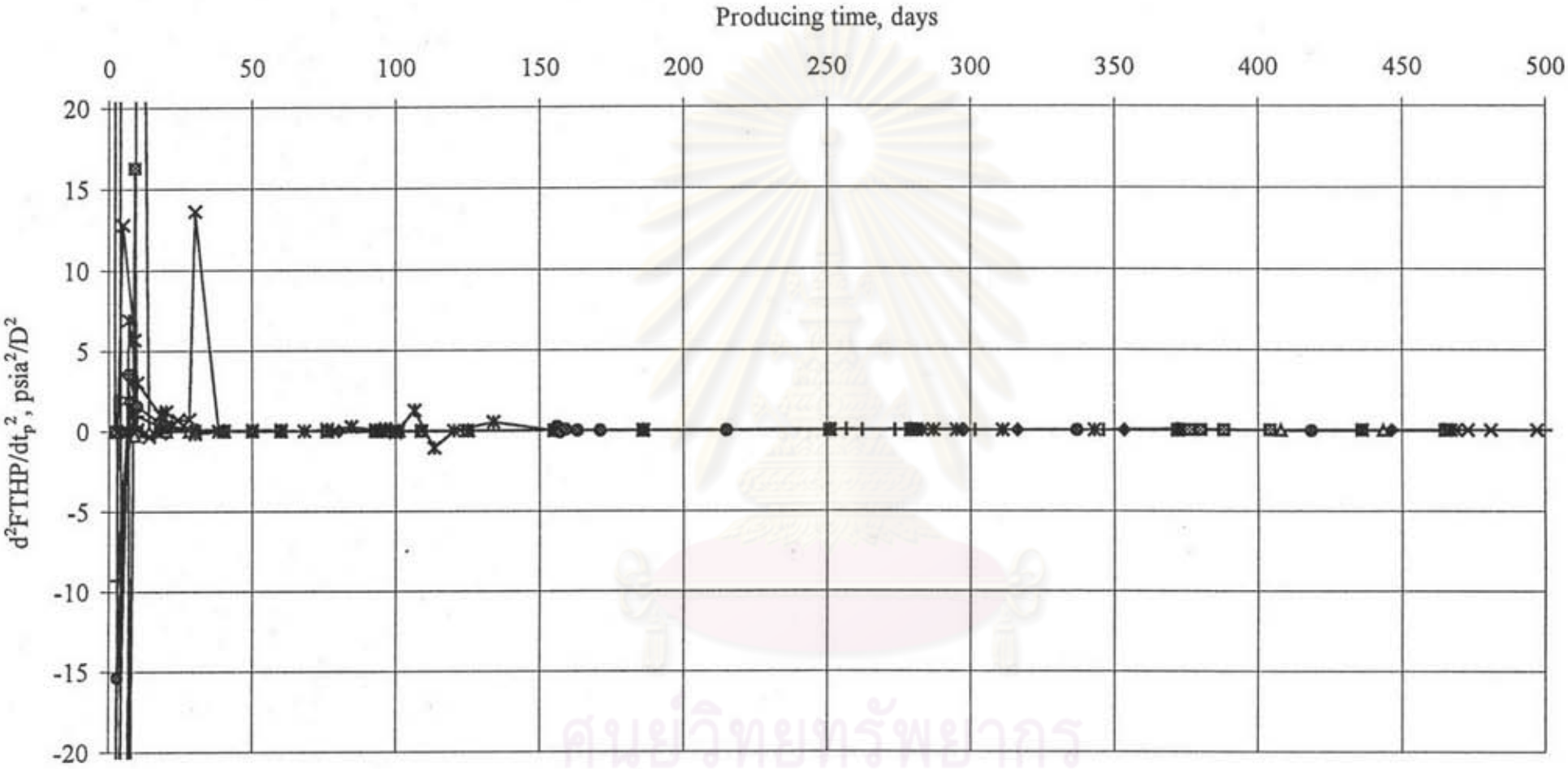

Figure 8.22 The second order derivative of flowing tubing head pressure with respect to time of the cases in the group having minimum flowing tubing head pressure of 100 psia

of each group is similar to that of the other group, provided that the maximum allowable oil rates are equal. However, the difference is the duration of each portion of the curve. For instance, each portion of the plot of the first orfer derivative of GOR of the cases with 1,000 STB/D and 50 psia (Figure 8.7) is smaller than that of the case with 1,000 STB/D and 100 psia (Figure 8.19).

The plot of the first order derivative of flowing tubing head pressure of both two groups are similar. The cases with very high maximum allowable oil rates have the derivatives which approach zero value in short time while the cases with very low maximum allowable oil rates have the derivative which approach zero value in long time. There is a case which has the curve which approaches zero value in between the curves of these two groups. This similarity is expected from the cases with minimum flowing tubing head pressures of 150 psia either.

Figure 8.23 is a comparison of oil production rate of the cases with minimum flowing tubing head pressure is set to 150 psia. It is found from these cases that the oil production rates of the cases in this groups are similar to those of the first two groups.

Figure 8.24 is a plot of GOR curves obtained from each case in this 150-psia group. The shape of GOR of each case is similar to that of other case. It could be seen that when GOR becomes greater than initial gas oil ratio, the slopes of GOR of all cases become similar to each other.

Flowing tubing head pressure plotted against producing time of each case in this group is shown in Figure 8.25. The results which are similar to those of the first two groups are obtained. The cases with high maximum allowable oil rates have very more rapid flowing tubing head pressure drop than that of the cases with lower maximum allowable oil rate.

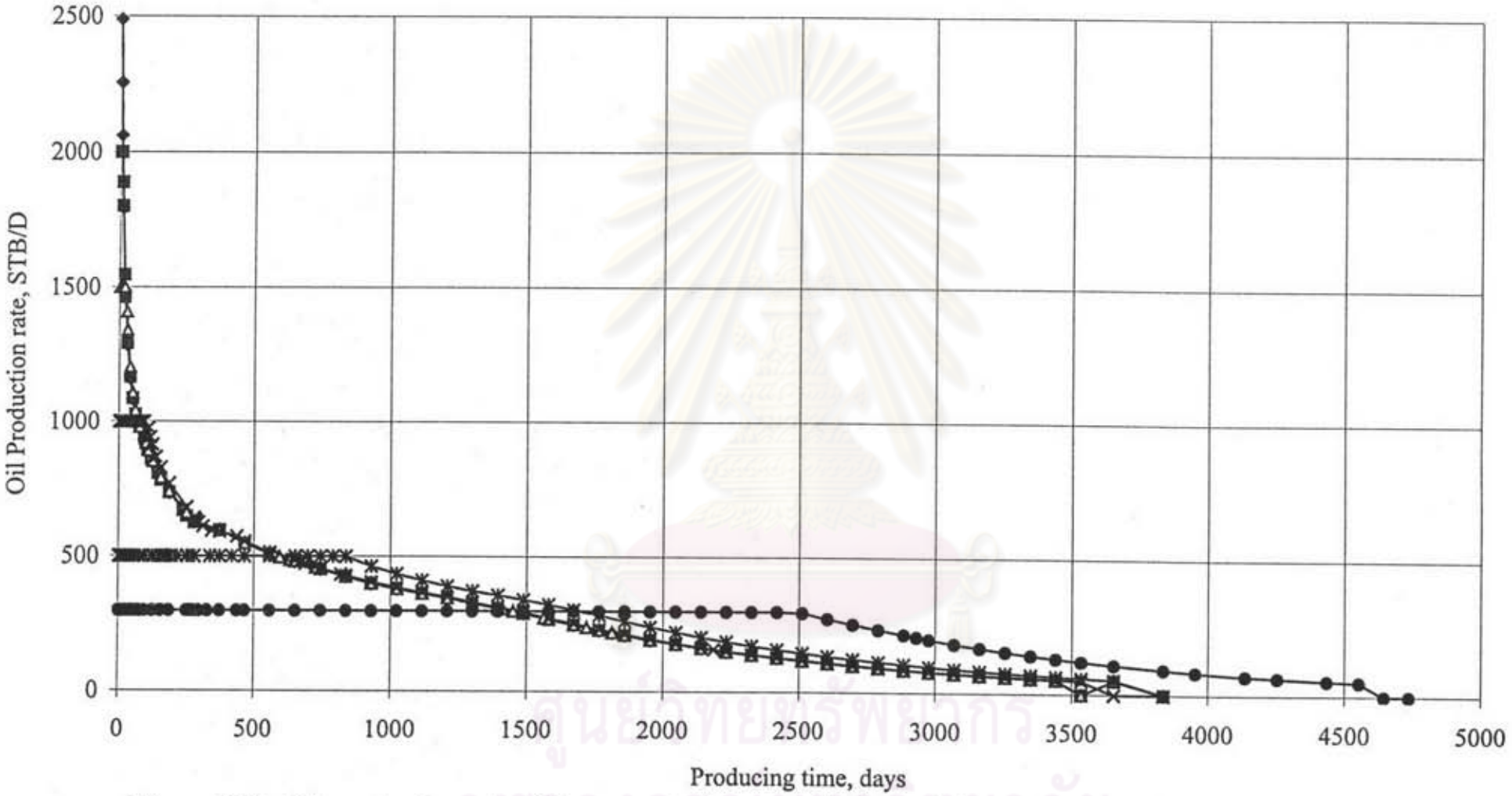

Figure 8.23 Oil production rate of the cases in the group having minimum flowing tubing head pressure of 150 psia

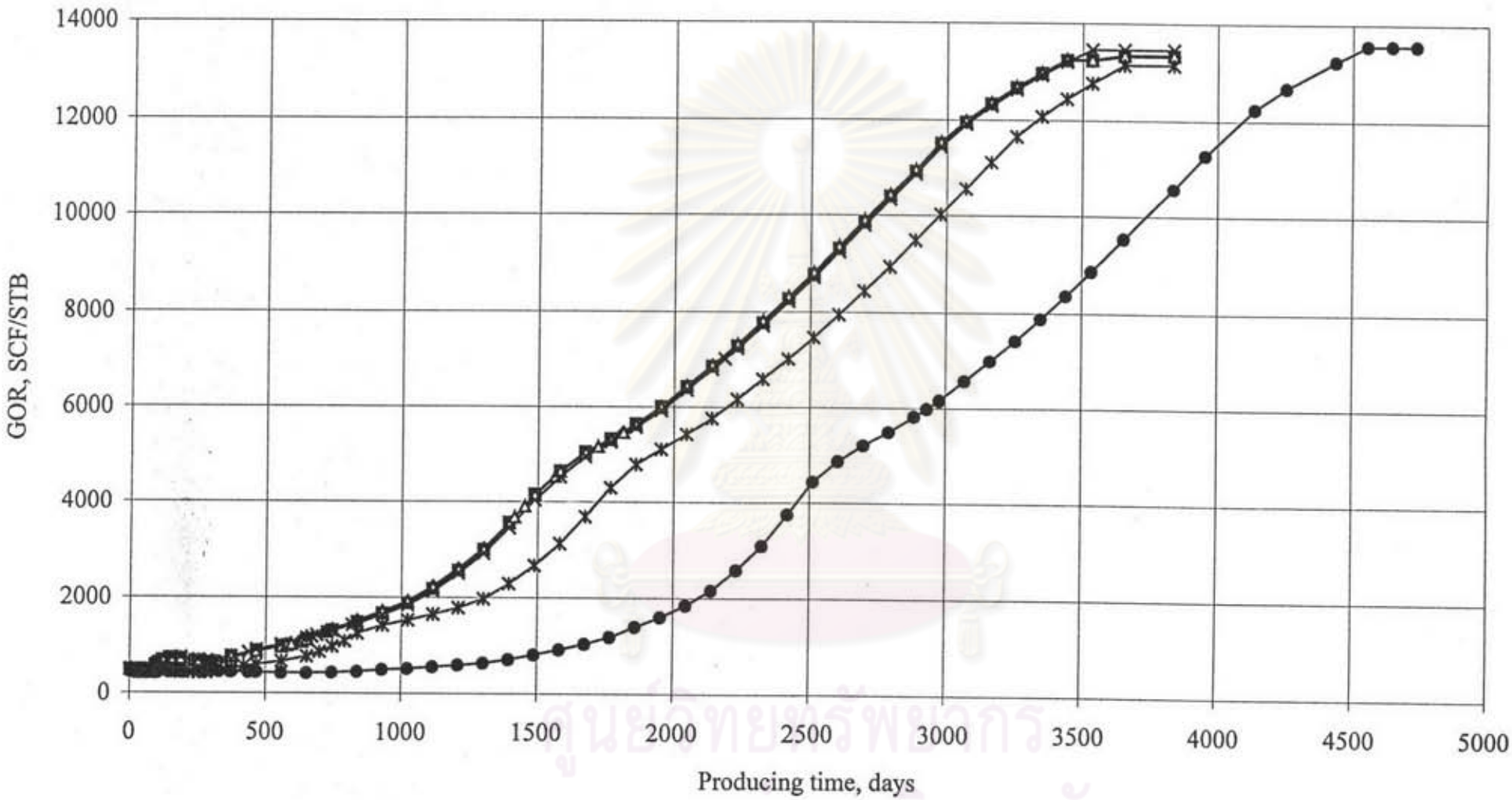

Figure 8.24 GOR of the cases in the group having minimum flowing tubing head pressure of 150 psia

Maximum allowable oil rate

Qo = 2488 STB/D — Qo = 2000 STB/D — Qo = 1500 STB/D — Qo = 1000 STB/D — Qo = 500 STB/D — Qo = 300 STB/D

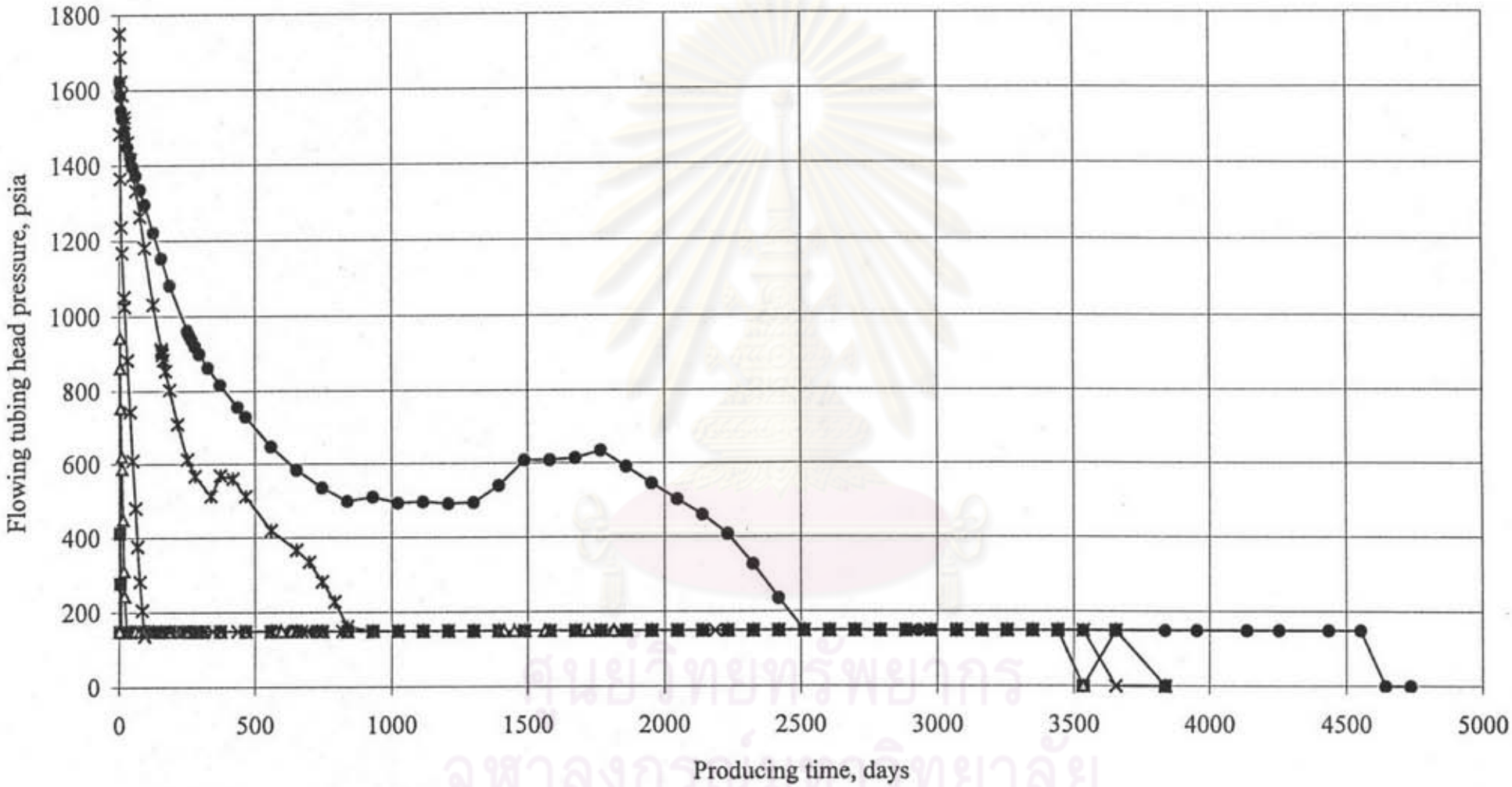

Figure 8.25 Flowing tubing head pressure of the cases in the group having minimum flowing tubing head pressure of 150 psia

Oil recovery fraction are plotted against producing time, as shown in Figure 8.26. The cases with maximum allowable oil rate of 1,000 STB/D or greater have similar curves. It is seen in the first two groups, which minimum flowing tubing head pressures are set to 50 and 100 psia respectively, and from the plot of this group that the difference of oil recovery fractions of the cases which maximum allowable oil rates of 1,000 STB/D or greater are very small.

Figure 8.27 represents the first order of oil flow rate with respect to producing time plotted against producing time. It is found that the shape of this derivative is similar to those of the previous two groups. Thus it can not be used for indicating the time when an increasing production process is required. The second order derivative of oil rate shown in Figure 8.28 could not be used as well since the curves in that plot have no unique shape.

The first and second order derivative of GOR of the cases in this group which has minimum flowing tubing head pressure of 150 psia are plotted in Figure 8.29 and 8.30, respectively. It is shown here that the shapes of the first order derivative of GOR curve of each case are similar to those of the first two groups which have minimum flowing tubing head pressure set to 50 and 100 psia. Thus the plot of the first order derivative of GOR can not be used. The shape of the second order derivative of GOR of each case is different from that of other cases. This type of plotted can not be used either.

The first order derivative of flowing tubing head pressure with respect to producing time is plotted against producing time, as shown in Figure 8.31. The curves obtained from the cases with high maximum allowable oil rates reach zero at early stage. The cases with low maximum allowable oil rates still have the derivative approach zero value at longer time while the case with maximum allowable oil rate of

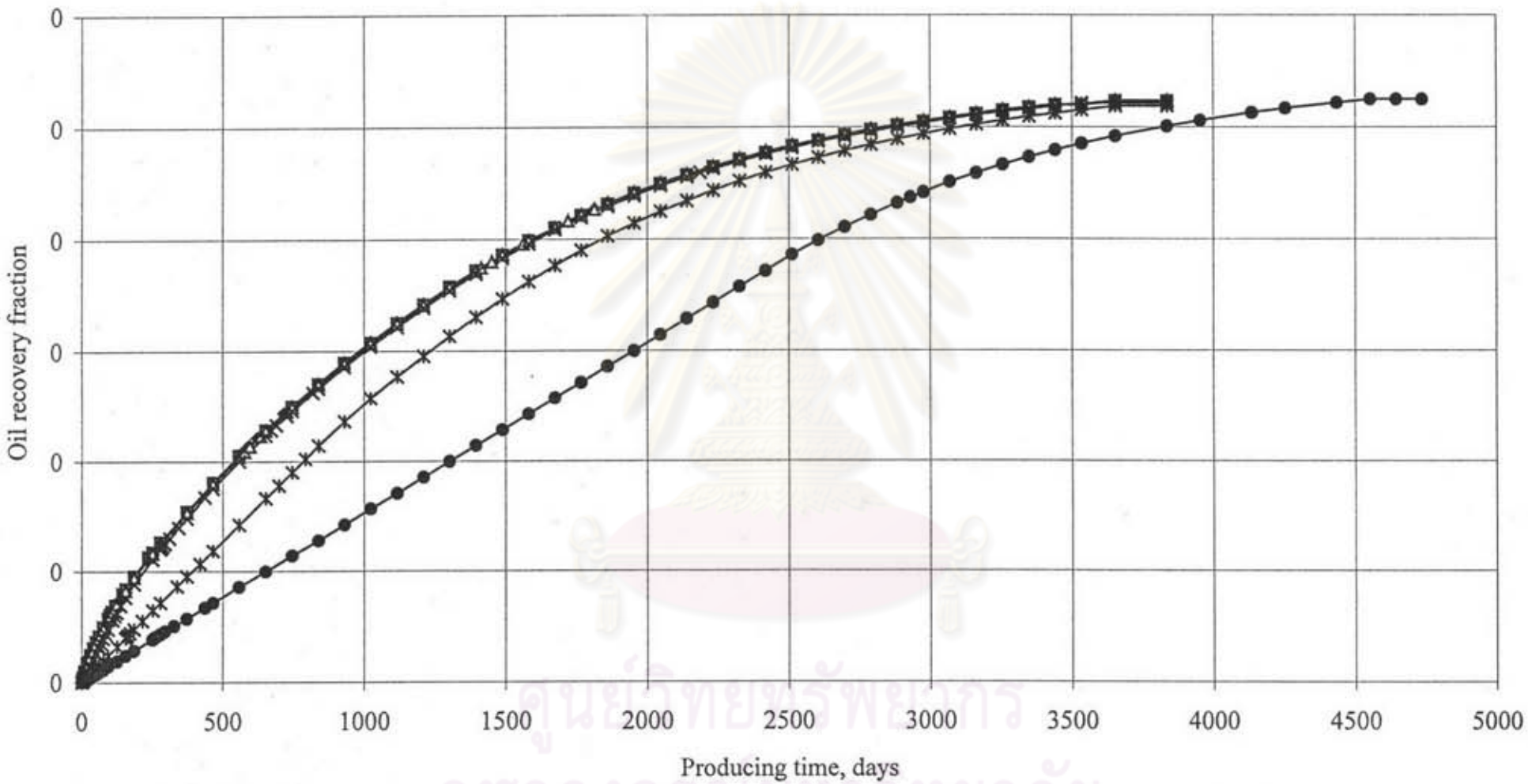

Figure 8.26 Oil recovery fraction of the cases in the group having minimum flowing tubing head pressure of 150 psia

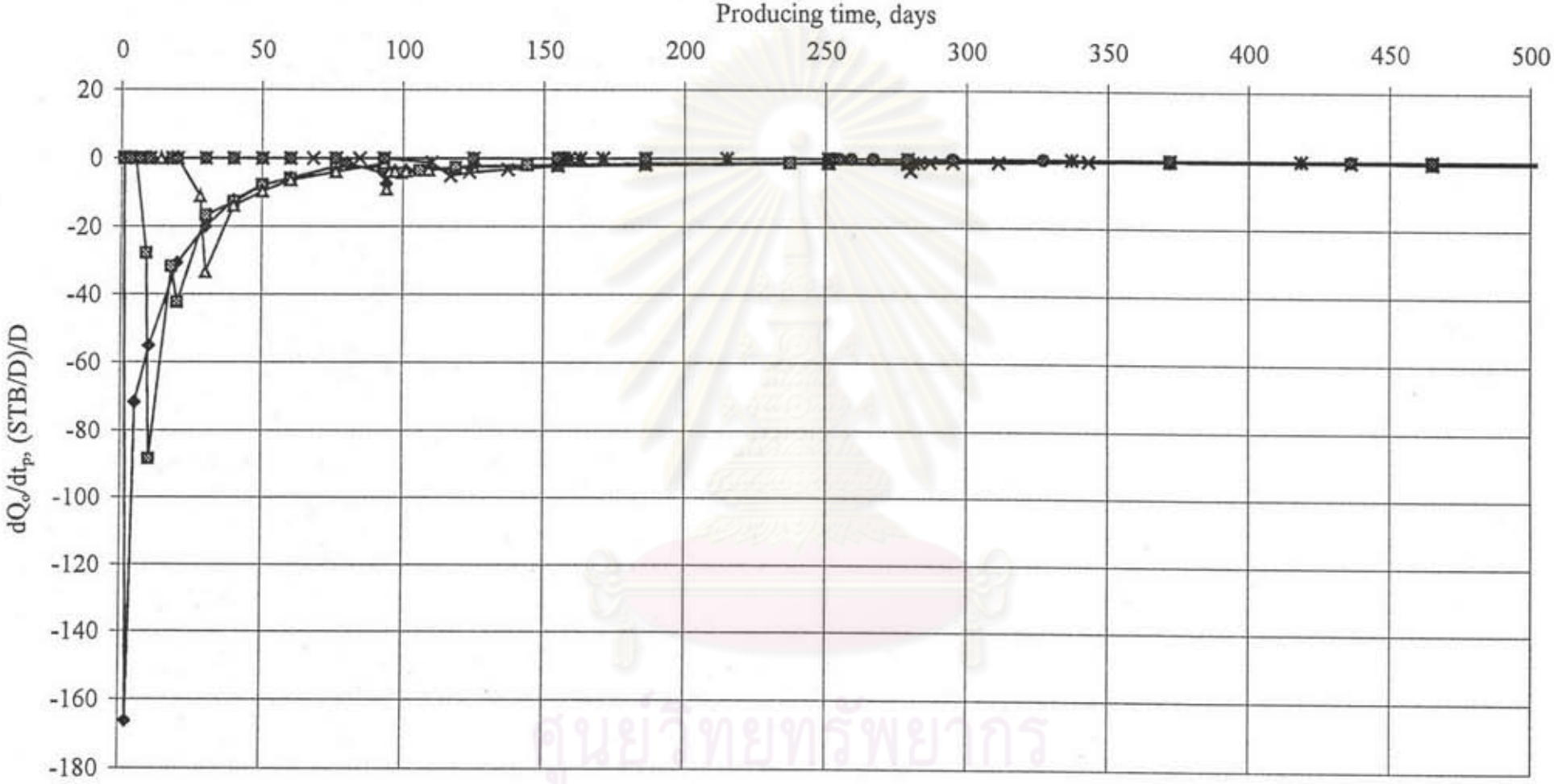

Figure 8.27 The first order derivative of oil rate with respect to time of the cases in the group having minimum flowing tubing head pressure of 150 psia

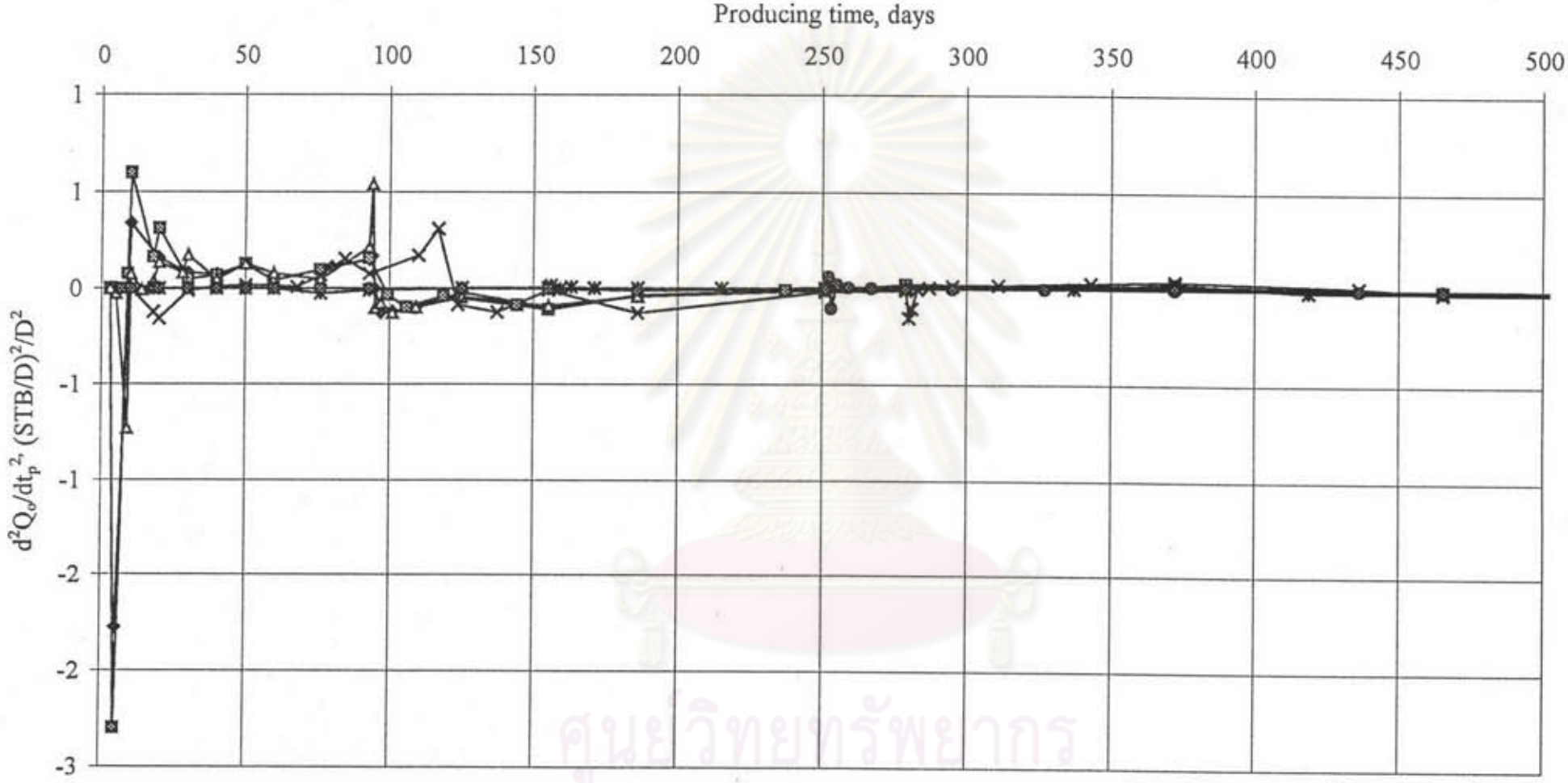

Figure 8.28 The second order derivative of oil rate with respect to time of the cases in the group having minimum flowing tubing head pressure of 150 psia

Maximum allowable oil rate

Qo = 2488 STB/D Qo = 2000 STB/D Qo = 1500 STB/D Qo = 1000 STB/D Qo = 500 STB/D Qo = 300 STB/D

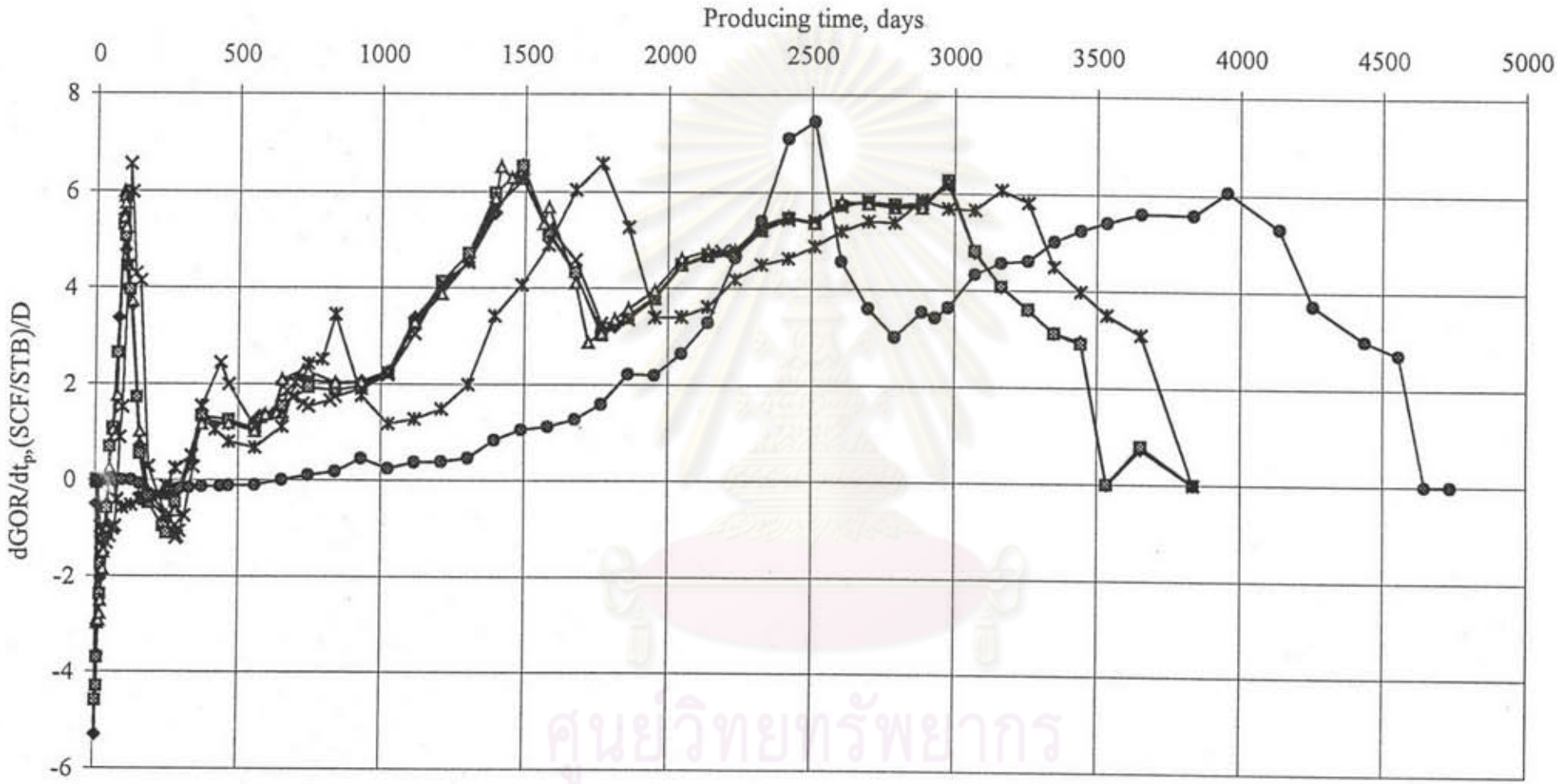

Figure 8.29 The first order derivative of GOR with respect to time of the cases in the group having minimum flowing tubing head pressure of 150 psia

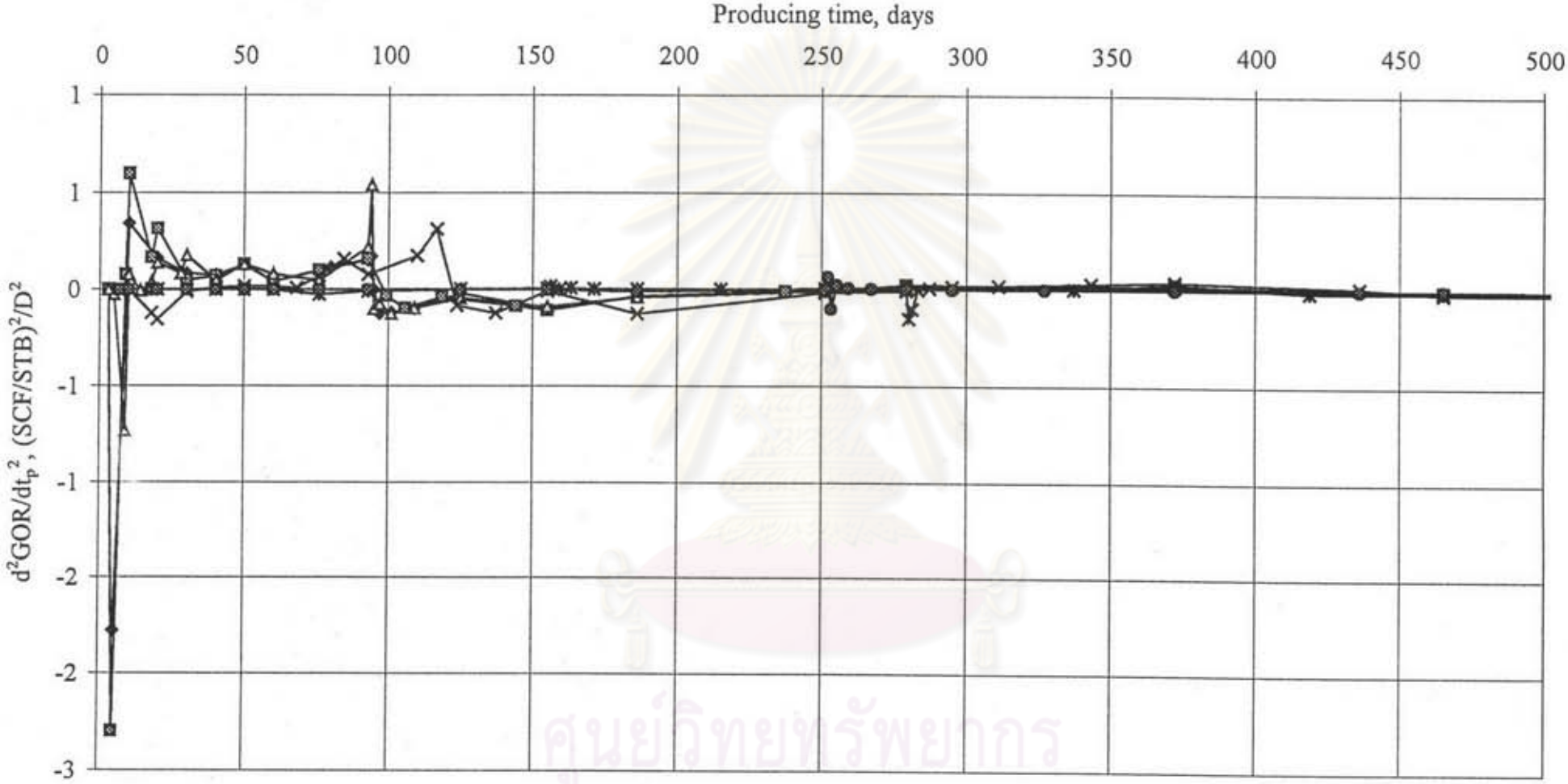

Figure 8.30 The second order derivative of GOR with respect to time of the cases in the group having minimum flowing tubing head pressure of 150 psia

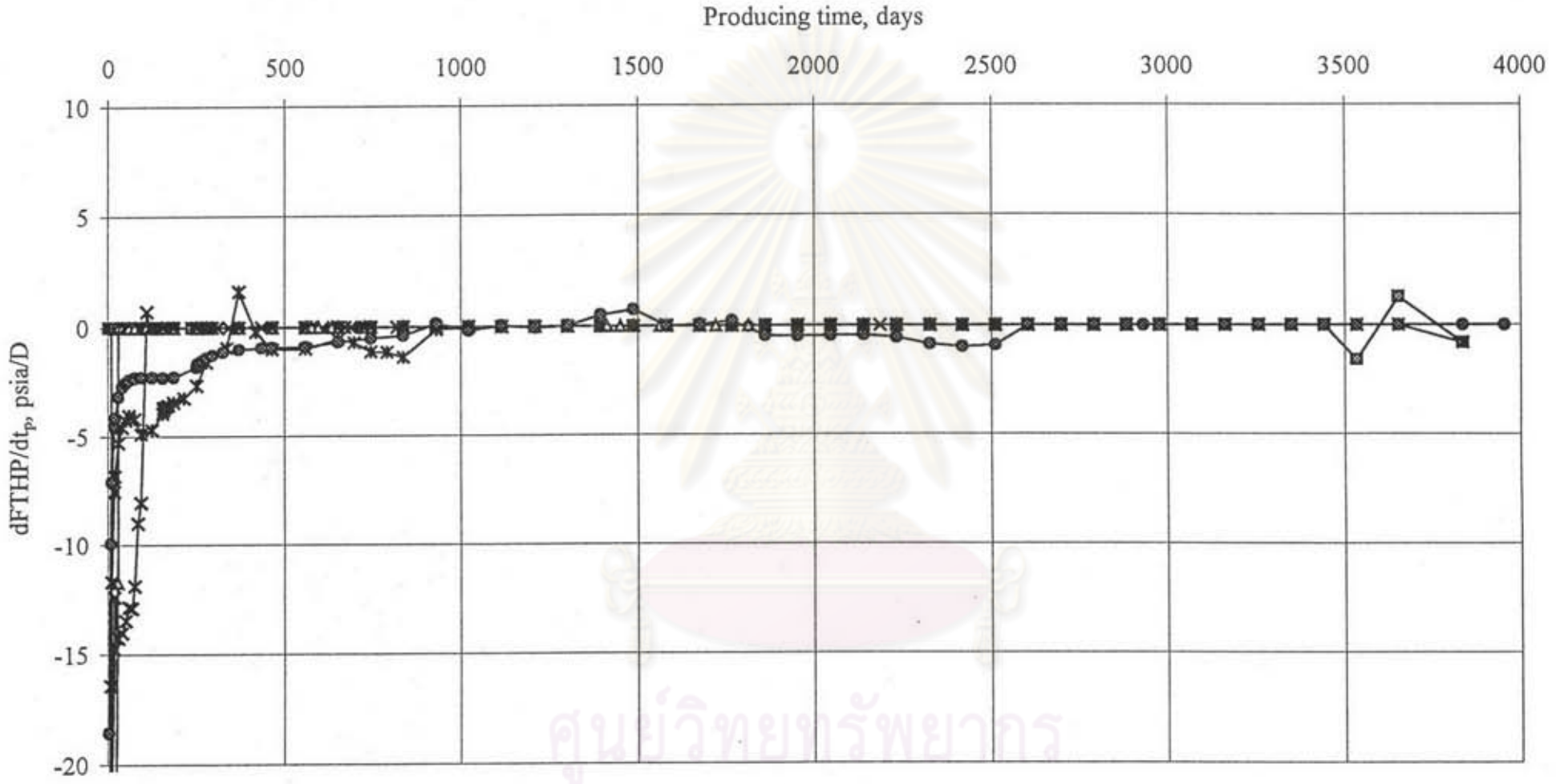

Figure 8.31 The first order derivative of flowing tubing head presssure with respect to time of the cases in the group having minimum flowing tubing head pressure of 150 psia

1,000 STB/D has the derivative approach zero value at intermediate time. The second order derivative of flowing tubing head pressure plotted against producing time is shown in Figure 8.32. The curves have similar characteristic to their previous counterparts.

The investigations made from the three groups of minimum flowing tubing head pressures show that there is a certain threshold oil production rate for this particular reservoir. The threshold rate refers to the minimum plateau rate which gives the optimum ultimate oil recovery. In addition, oil recovery fraction at any producing time obatined from producing at the threshold rate is very close to that of the case which the well is produced at higher plateau rate. The threshold rate of these cases is 1,000 STB/D. It is further considered about the variation of the shape of the first order derivative of flowing tubing head pressure of the cases with maximum allowable oil rates are between 500 and 1,000 STB/D. Therefore, a set of maximum allowable oil rates varying between 500 and 1,000 STB/D is simulated to visualize the shape of this derivative. It is seen from the three groups that the application of the first order derivative of flowing tubing head pressure is not affected by the variation of minimum flowing tubing head pressure. Hence the minimum flowing tubing head pressure of 50 psia is used for further investigations. The plots of the case with 1,500 STB/D is also included for comparison purpose.

Figure 8.33 represents the comparison of oil production rates varying between 500 and 1,500 STB/D. It is shown in this figure that the case with 1,500 STB/D has a production profile with rapid decline. The cases with 800 STB/D or greater have almost identical production profiles. Thus, it is expected that plots of other information of the cases with 800 STB/D or greater are similar.

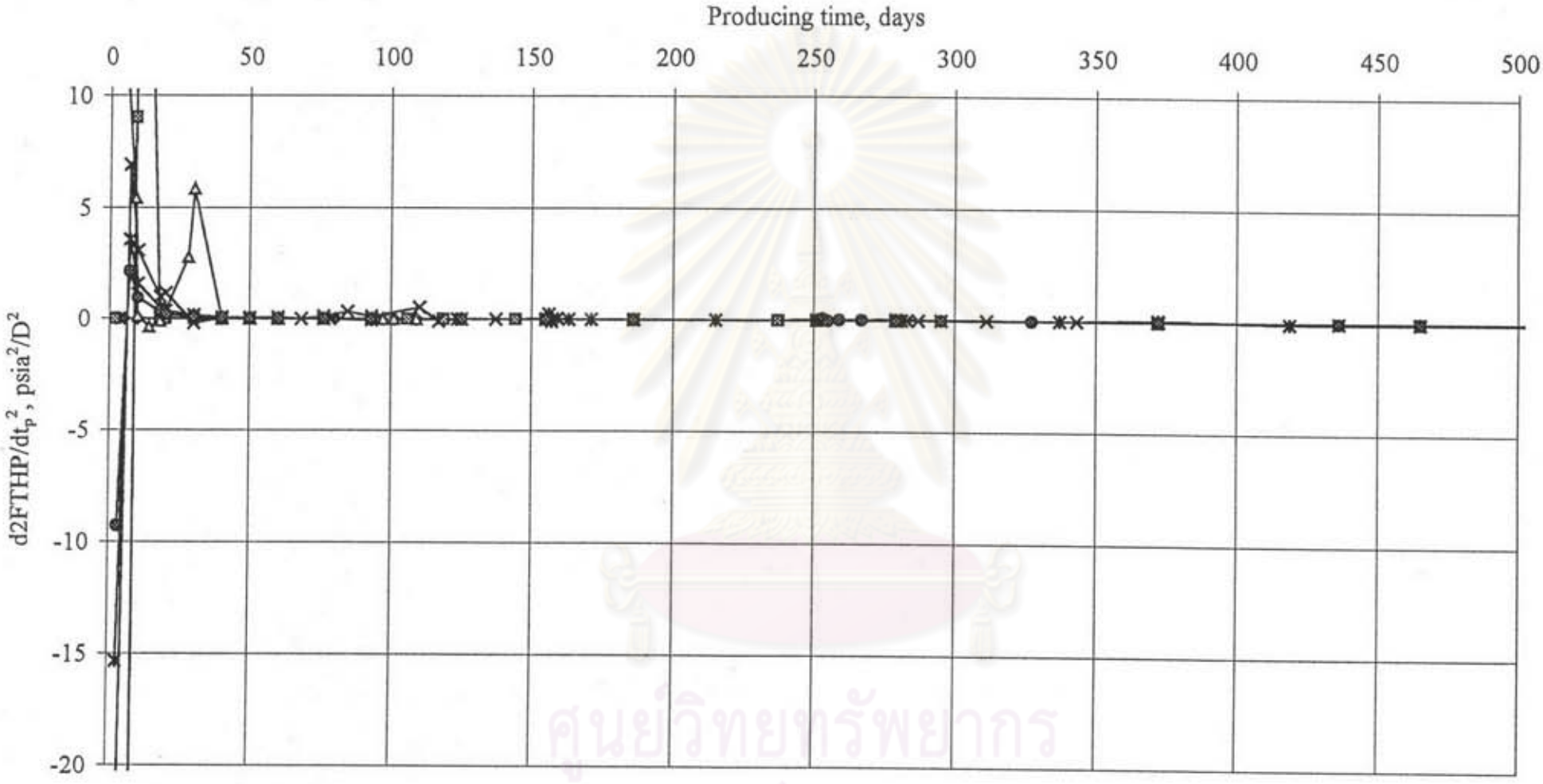

Figure 8.32 The second order derivative of flowing tubing head pressure with respect to time of the cases in the group having minimum flowing tubing head pressure of 150 psia

Maximum allowable oil rate

Qo = 2488 STB/D Qo = 2000 STB/D Qo = 1500 STB/D Qo = 1000 STB/D Qo = 500 STB/D Qo = 300 STB/D

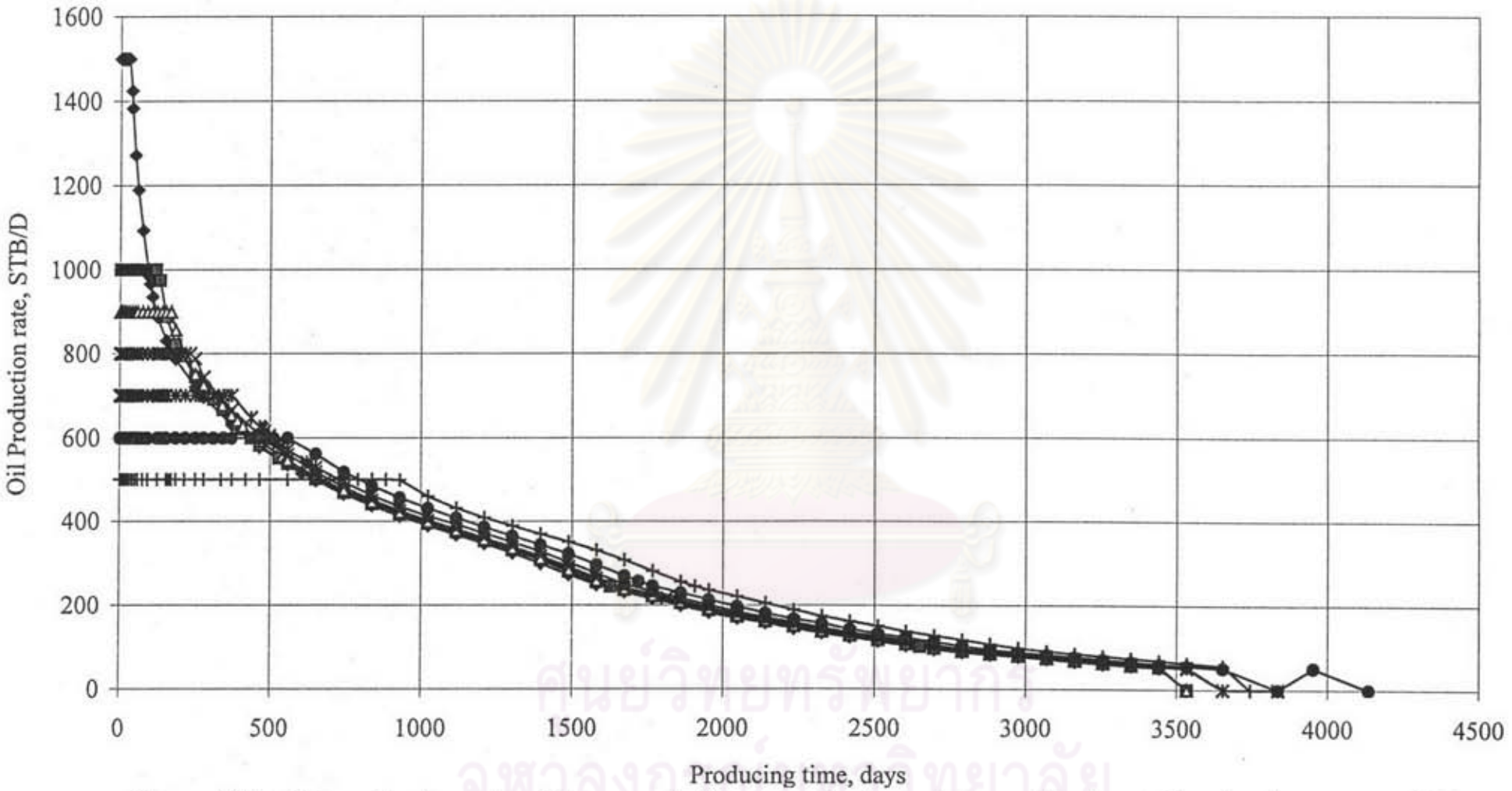

Figure 8.33 Oil production rate of the cases in the group having minimum flowing tubing head pressure of 50 psia

A plot of GOR obtained from each maximum allowable oil rate is shown in Figure 8.34. It is confirmed from this plot that the behavior of GOR of the cases with 800 STB/D or greater are similar. Thus, it is expected that the plots of oil recovery, the first order derivative of GOR and the plot of derivative of flowing tubing head pressure of the cases with 800 STB/D or greater are similar. The exception is made to plot of flowing tubing head pressure shown in Figure 8.35. On the other hand, the shapes of flowing tubing head pressure of the cases with 800 STB/D or greater are different. However, the typical trend is still observed. The case with higher maximum allowable oil rate has more rapid drop in flowing tubing head pressure with no significant deflection.

The above investigation is partly confirmed by Figure 8.36 and Figure 8.37. Figure 8.36 is a plot of oil recovery plotted against producing time and Figure 8.37 is the first order derivative of GOR with respect to producing time plotted against producing time. These two plots have typical shapes as found previously. Figure 8.38 which represents a comparison of the first order derivative of flowing tubing head pressure with respect to producing time, shows that the shape of the curve is similar to those observed previously either. However, the distinction is observed. The time to reach zero of the curves vary accordingly to the maximum allowable oil rates. The curve with lower maximum allowable oil rate has longer time to reach zero than that of the case with higher maximum allowable oil rate. It could be noticed from this figure that the differences of time for the derivative of flowing tubing head pressure to reach zero between the cases with 800 STB/D or greater are not greater than 100 days. For example, the difference in time to reach zero of the derivative of the case with 1,000 STB/D and 900 STB/D is 60 days. This is practically considered negligible.

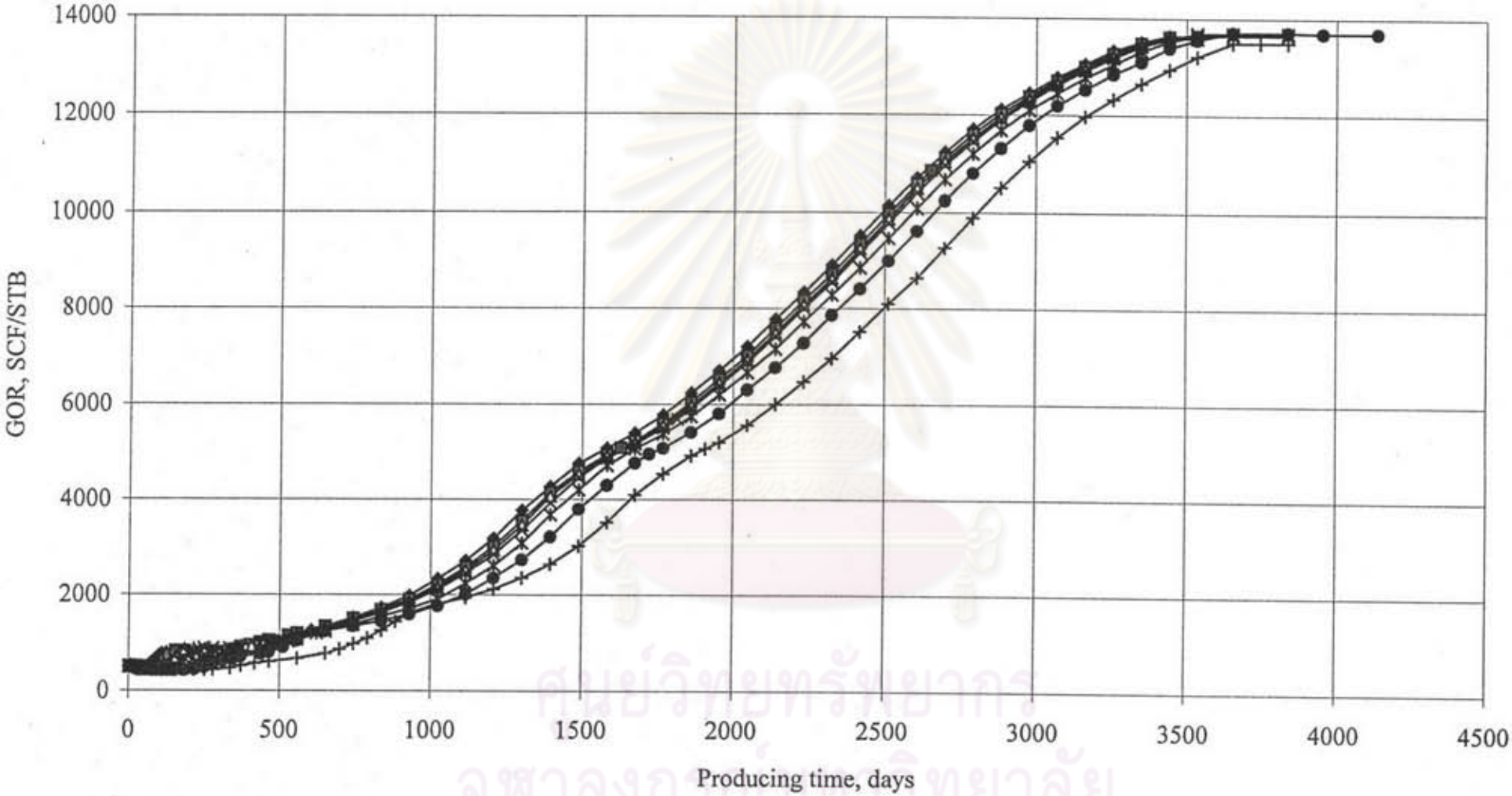

Figure 8.34 GOR of the cases in the group having minimum flowing tubing head pressure of 50 psia

Maximum allowable oil rate

Qo = 1500 STB/D Qo = 1000 STB/D Qo = 900 STB/D Qo = 800 STB/D Qo = 700 STB/D Qo = 600 STB/D Qo = 500 STB/D

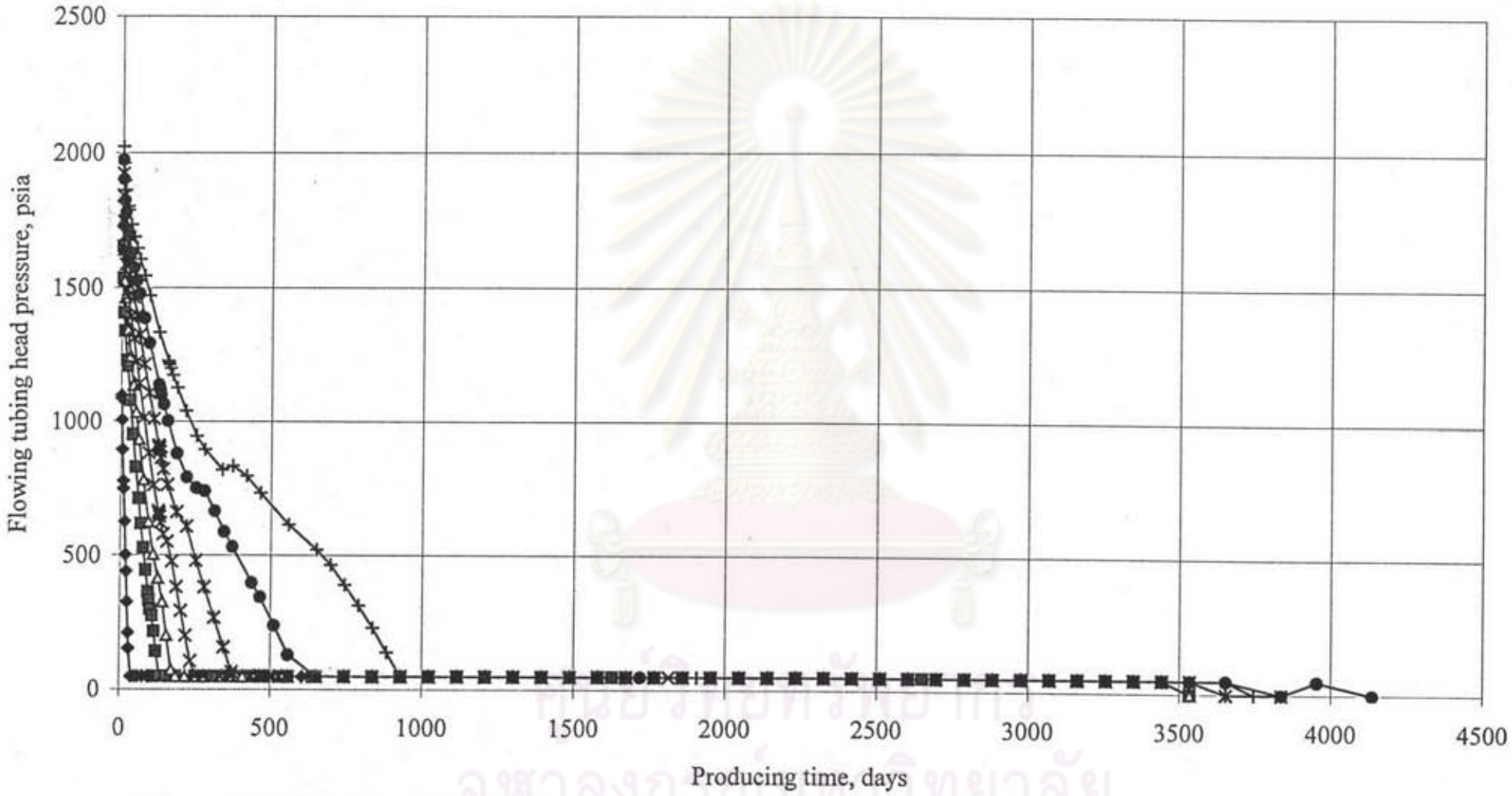

Figure 8.35 Flowing tubing head pressure of the cases in the group having minimum flowing tubing head pressure of 50 psia

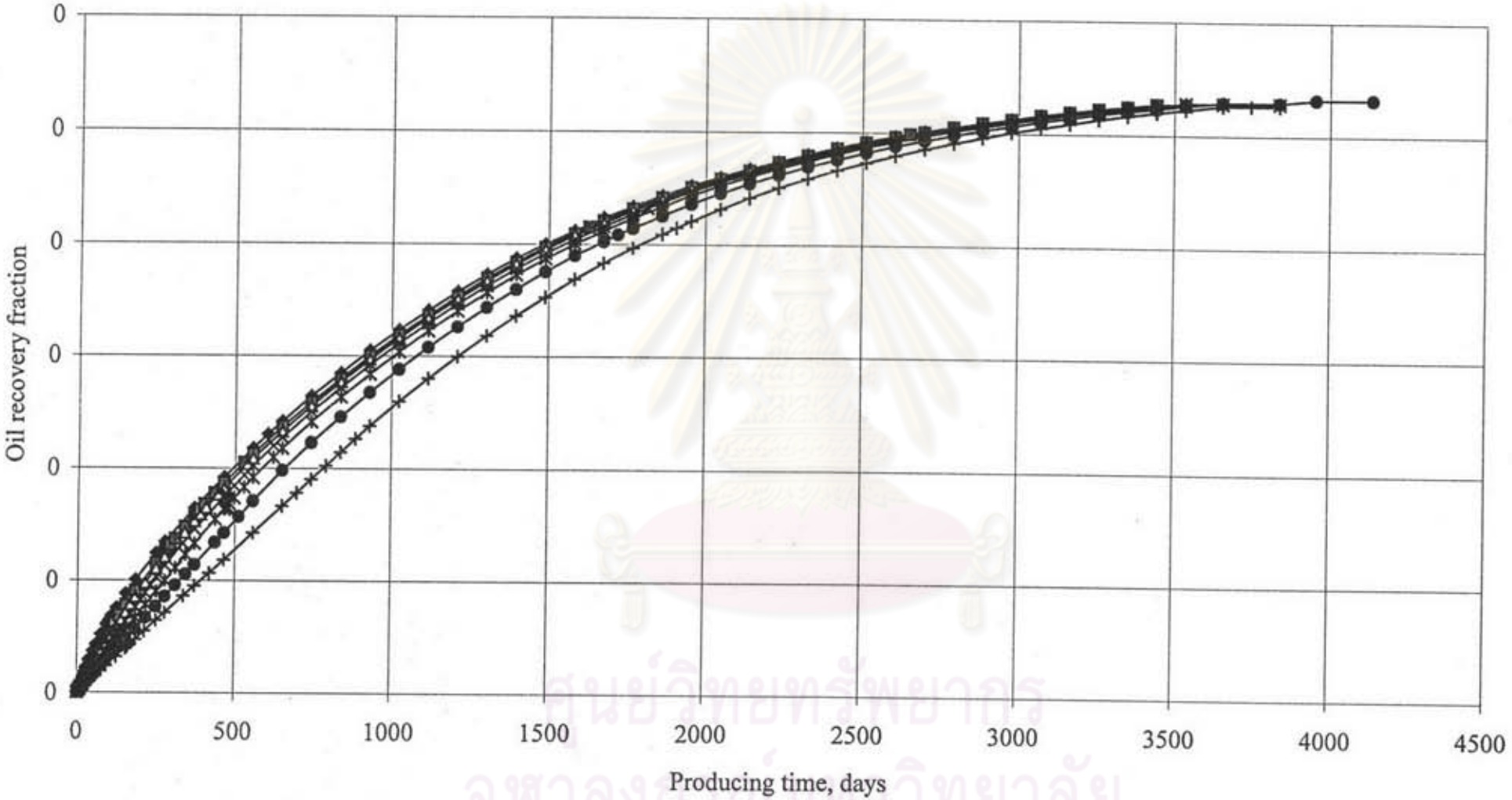

Figure 8.36 Oil recovery fraction of the cases in the group having minimum flowing tubing head pressure of 50 psia

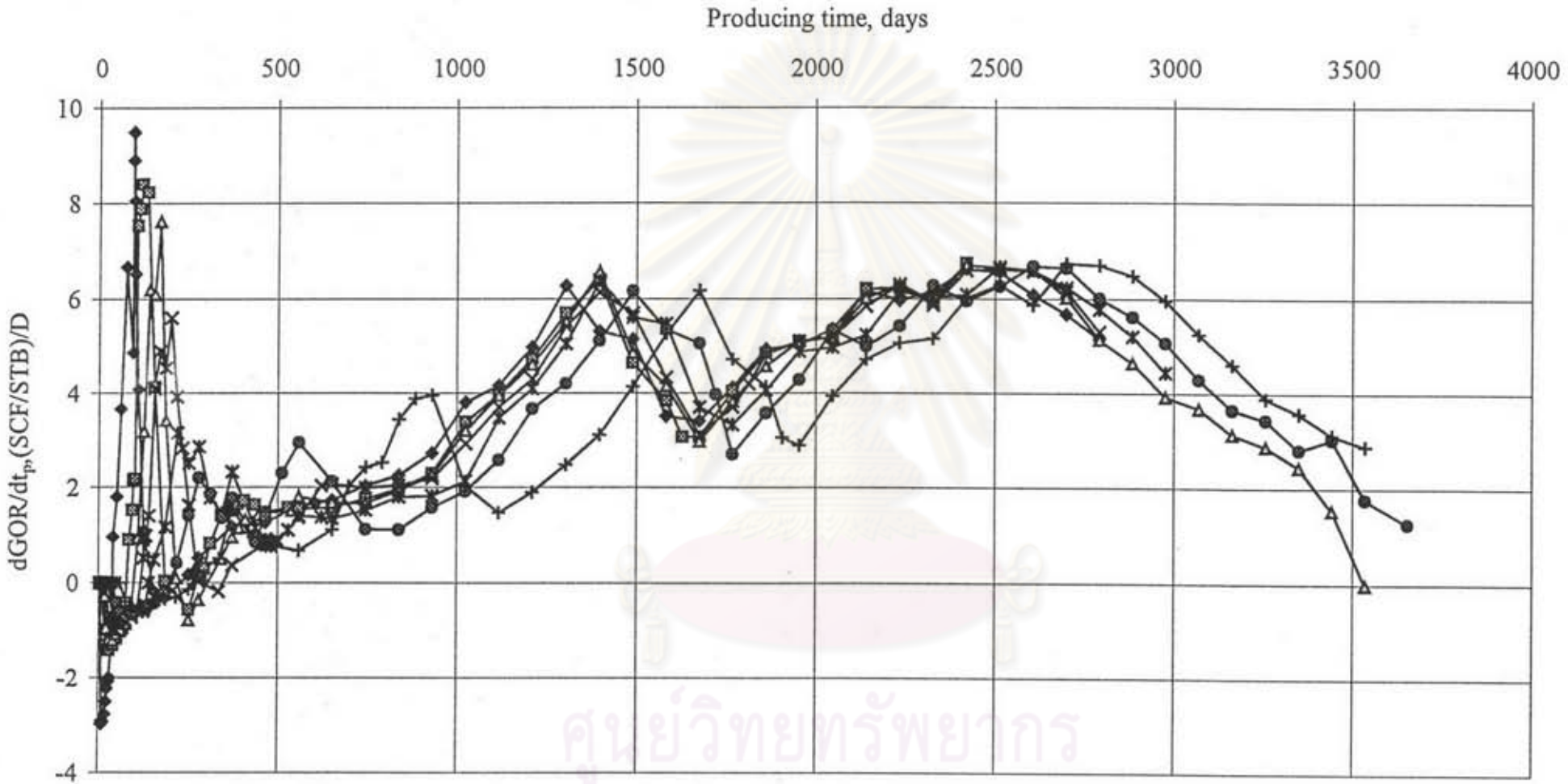

Figure 8.37 The first order derivative of GOR with respect to time of the cases in the grouph having minimum flowing tubing head pressure of 50 psia

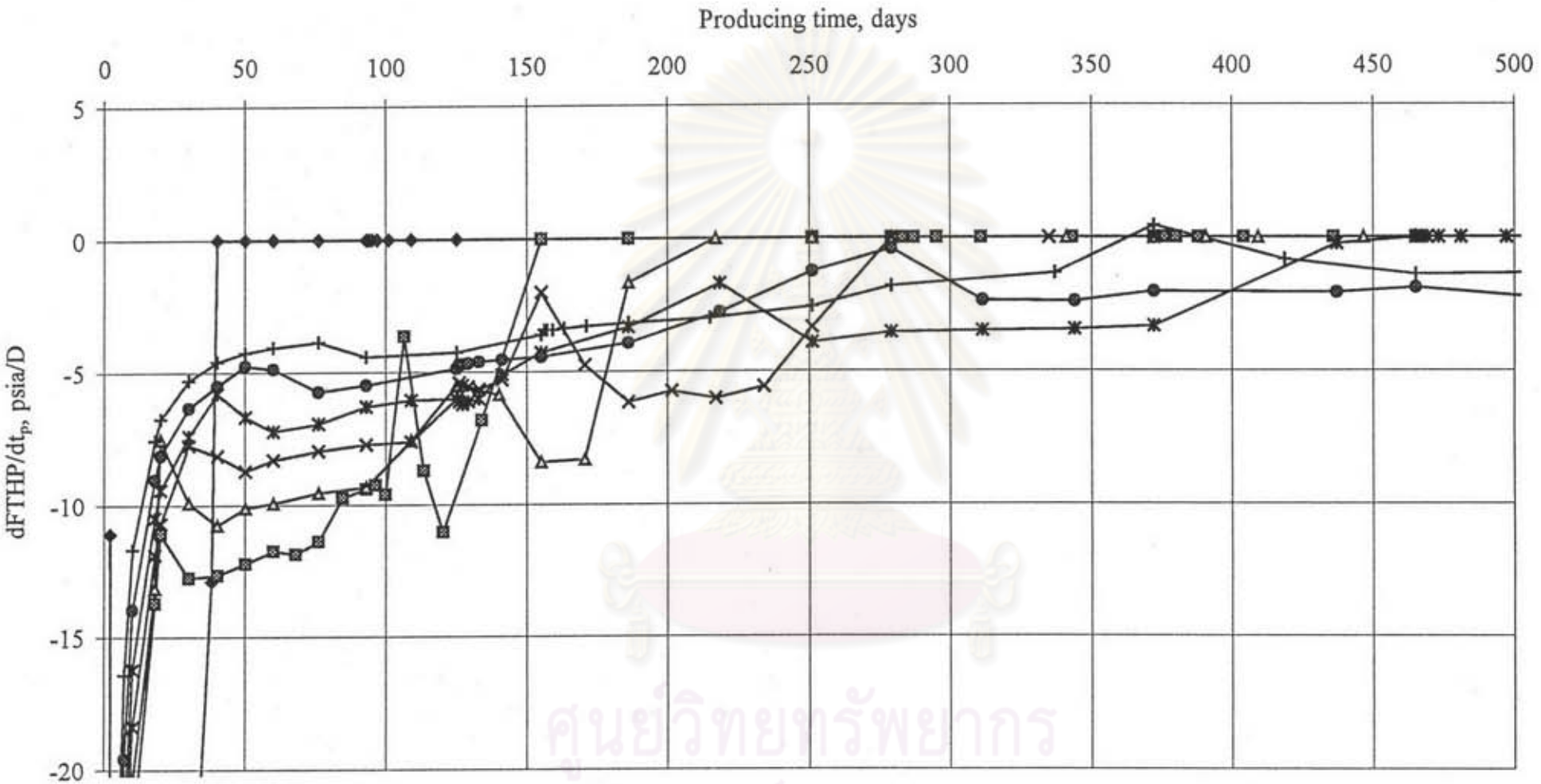

Figure 8.38 The first order derivative of flowing tubing head presssure with respect to time of the cases in the group having minimum flowing tubing head pressure of 50 psia

The derivative of flowing tubing head pressure can, therefore, be considered as an identifier which can be used for improving time to reach ultimate oil recovery. The application of this technique is to design an optimum plateau rate for a production well. The procedure is to have the well produce at any predetermined plateau rate. The first order derivative of flowing tubing head pressure with respect to producing time is, then, plotted against producing time from the beginning of the production life. The shape of the derivative must be investigated simultaneously. If it appears that the derivative shows the gently increasing trend and does not reach zero value within relatively short time, the plateau rate that the well has been producing is not considered as a threshold or optimum plateau rate. Thus, the production rate should be increased. The plot of the derivative should, however, be investigated continuously. When the production is changed, the derivative should have greater slope, i.e. the increasing rate should be faster than the previous portion. Note that when the production rate is increased, an abrupt drop of the derivative is noticed. It should be further noticed that it is possible to have the derivative of flowing tubing head pressure increase abruptly. The abrupt increase of the derivative of flowing tubing head pressure occurs when GOR is just greater than R_{si}. In this case, the plot of GOR against producing time is needed to explain the cause of abrupt incrase of the derivative.