CHAPTER IV
GAS STORAGE PROGRAM

The numerical method called, the implicit alternating-direction method (IAD), is used to solve the gas storage problem, which is the partial differential equation.

4.1 Perturbation Analysis

When the finite-difference method was programmed, the perturbation analysis was used to check the program. The system was disturbed and the data was recorded until reaching steady state. The advantage of perturbation analysis is to test if the program that you write makes sense or not.

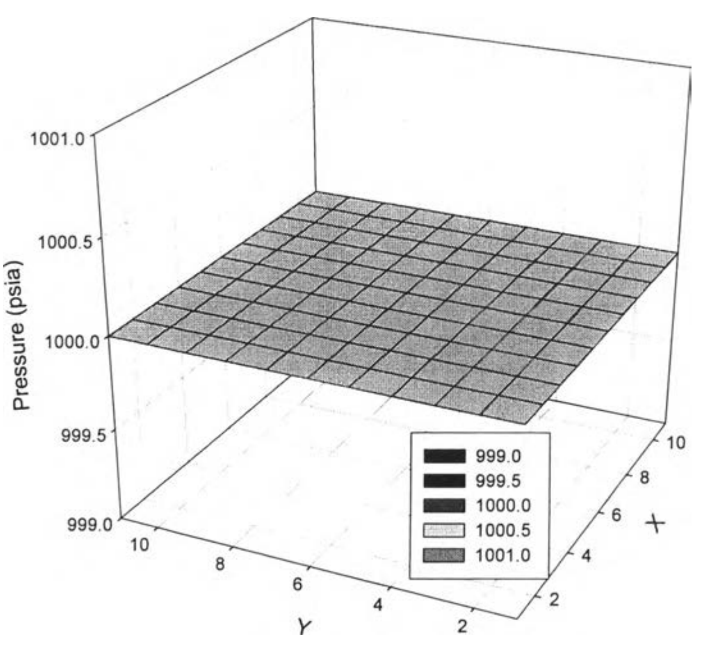


Figure 4.1 Pressure profile at t = 0 second.

The Figure 4.1 shows the initial profile before perturbation. The example problem consists of eleven rows and columns and the member of grid point 1,000. The perturbation is happened at grid point of (6, 6) in row and column and the value of these point is100 psia. For test the numerical subroutine in the program, the result will show in graphically in Figure 4.2. Figure 4.2 is the pressure profile showed in 3-dimension and the Figure 4.2 is the top view of pressure profile.

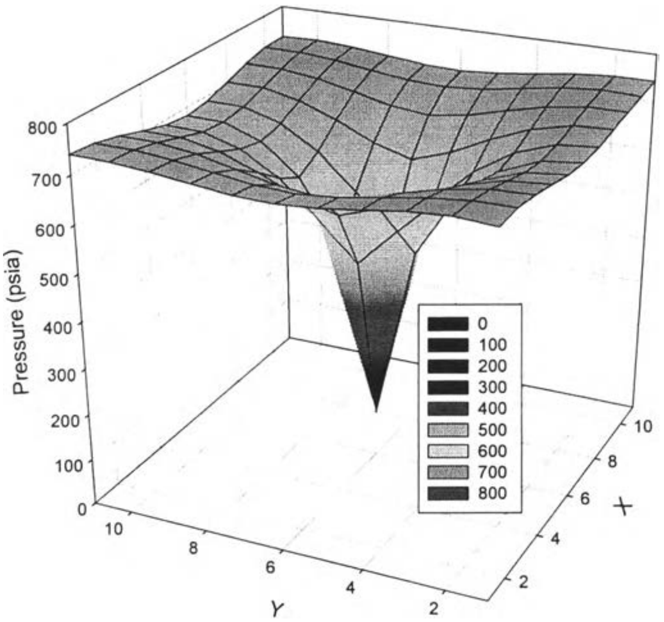


Figure 4.2 Pressure profile at t = 20 second.

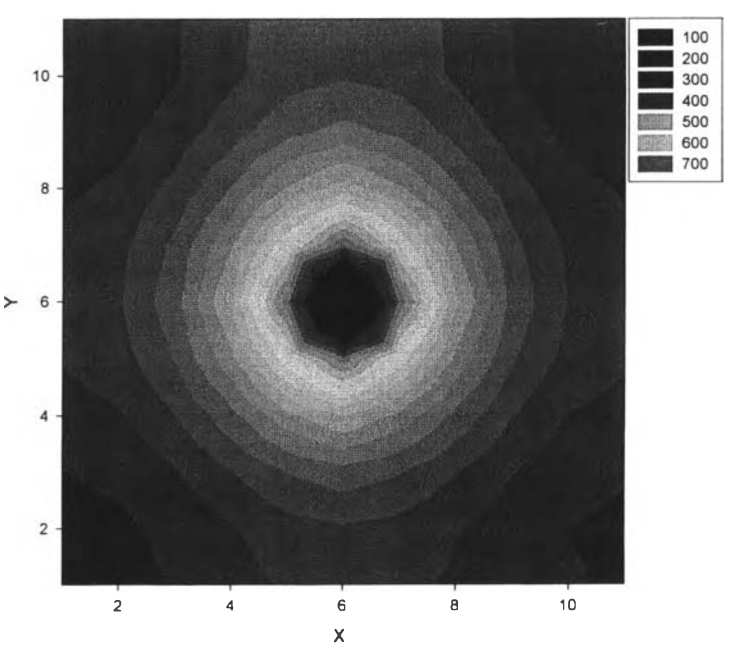


Figure 4.3 Cross sectional view of pressure profile at t = 20 second.

For Figure 4.2, you can see the result from perturbation after run for 20 second. The values are reduce rapidly near the disturbed point.

4.2 Main Program

When the program is tested by the initial perturbation, the numerical method will be applied to solve the problem. The basic problem data are 4,000 ft long and 4,000 ft wide.

4.2.1 Regular Shape

From the work, the first program is applied to solve the problem in regular shape.

4.2.1.1 Constant Permeability

The constant permeability is a simple case to test that the main program is correct and other input data can see be in appendix.

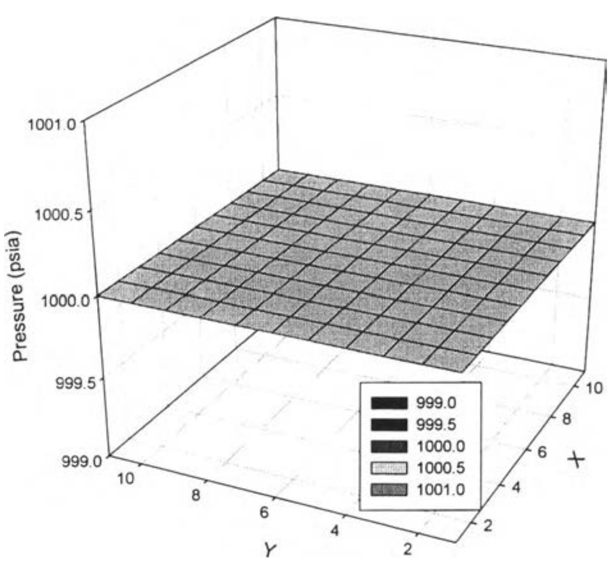


Figure 4.4 Pressure profile at t = 0 second.

In the problem of natural gas storage, the well is located at grid point (8, 8). From the gas storage program can predict the pressure profile that are shown in Figure 4.5 and Figure 4.6.

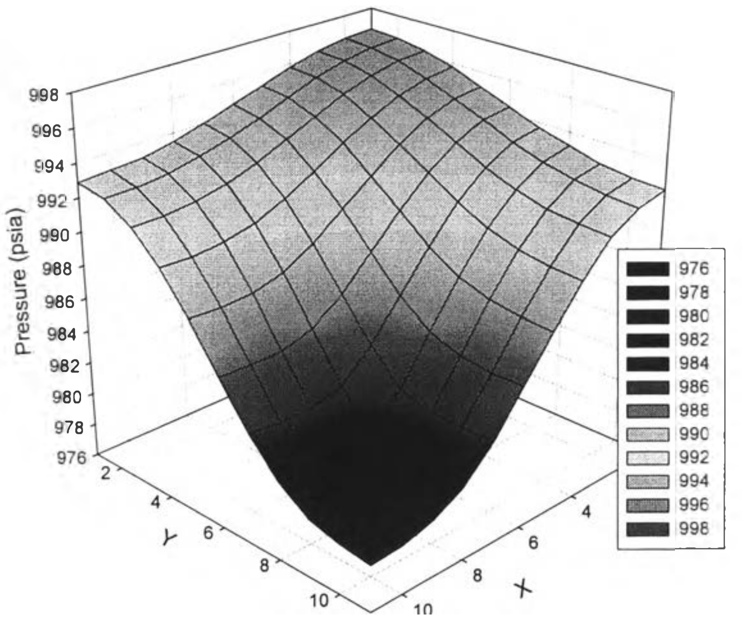


Figure 4.5 Pressure profile at t = 10 second.

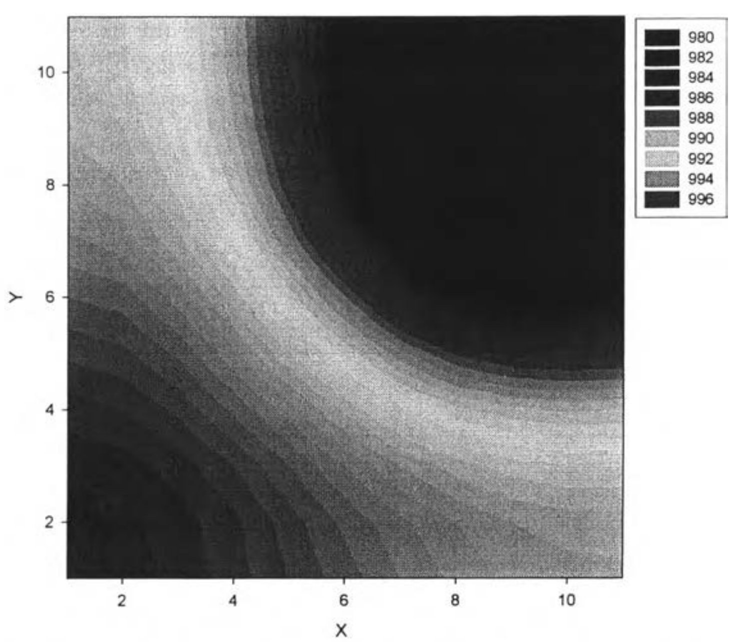


Figure 4.6 Cross sectional view of pressure profile at t = 10 second.

The picture shows the pressure profile in the gas storage reservoir predicted by the gas storage program. From this case, the well is located at grid (8, 8). The pressure near the well is lower than the surrounding pressure outside.

4.2.1.2 Inconstant Permeability

In the real world, the permeability of the reservoir is not constant. So, the good simulation program should predict the pressure profile in the reservoir.

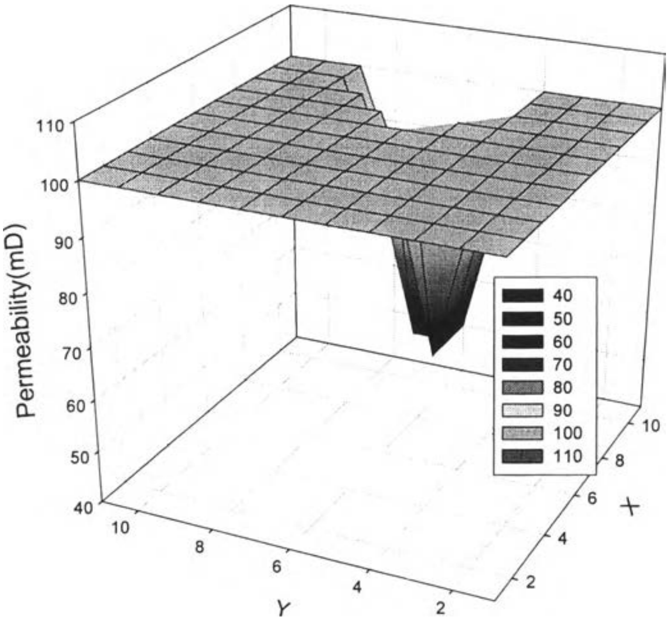


Figure 4.7 Permeability profile (input data).

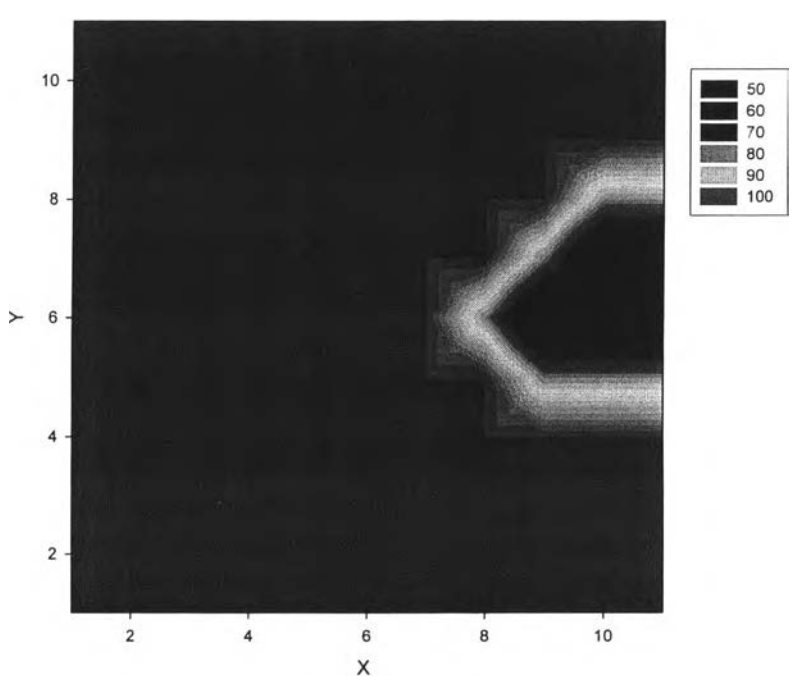


Figure 4.8 Cross sectional view of permeability profile.

From the Figure 4.7 and Figure 4.8, unstable permeability profile of reservoir is shown in graphically.

Case 1

For case 1, the well is located at grid point (6, 6) high and stable permeability reservoir. The result will be shown in Figure4.9.

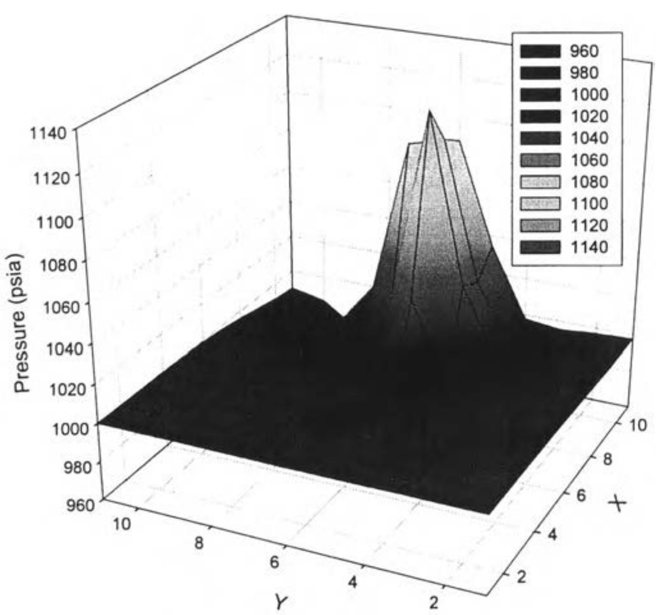


Figure 4.9 Pressure profile at T = 10 days.

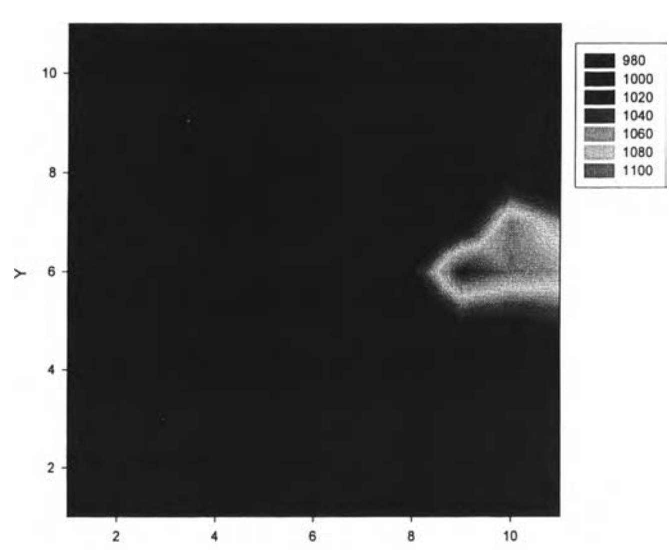


Figure 4.10 Cross sectional view of pressure profile at T = 10 days.

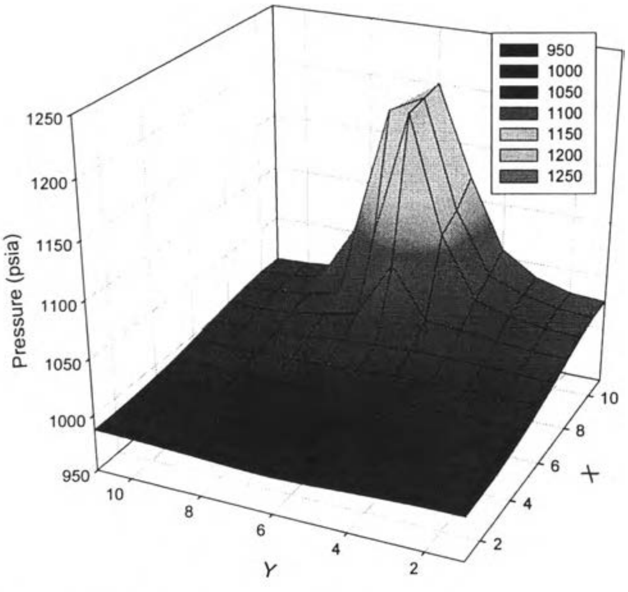


Figure 4.11 Pressure profile at T = 100 days.

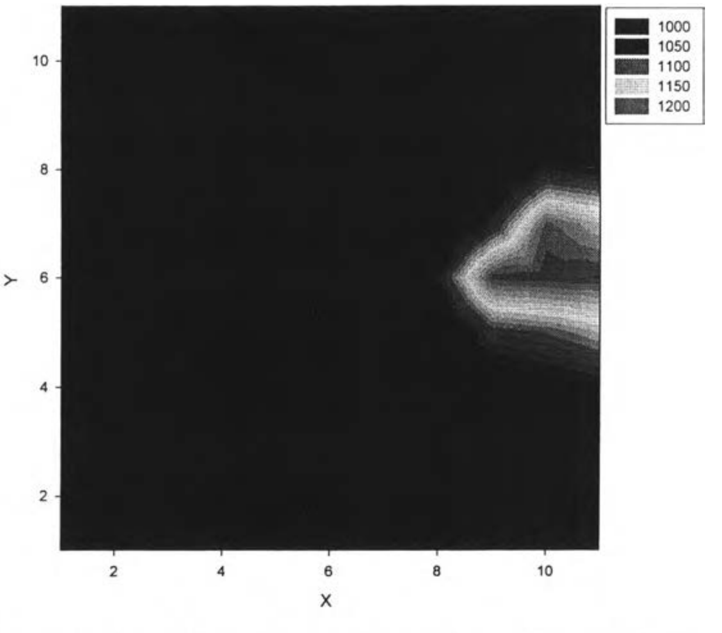


Figure 4.12 Cross sectional view of pressure profile at T = 100 days.

When the well is located at (x, y) = (6, 6), the result shows that the pressure profile near the well is lower than some other and the pressure of the well is the lowest. The high pressure profile represents in red color and the blue color represent in low pressure. From the result, the natural gas moves from high pressure that is agreement with the problem that test before.

Case 2

For case 2, the well is located at high and unstable permeability. The result will be shown in Figure 4.13.

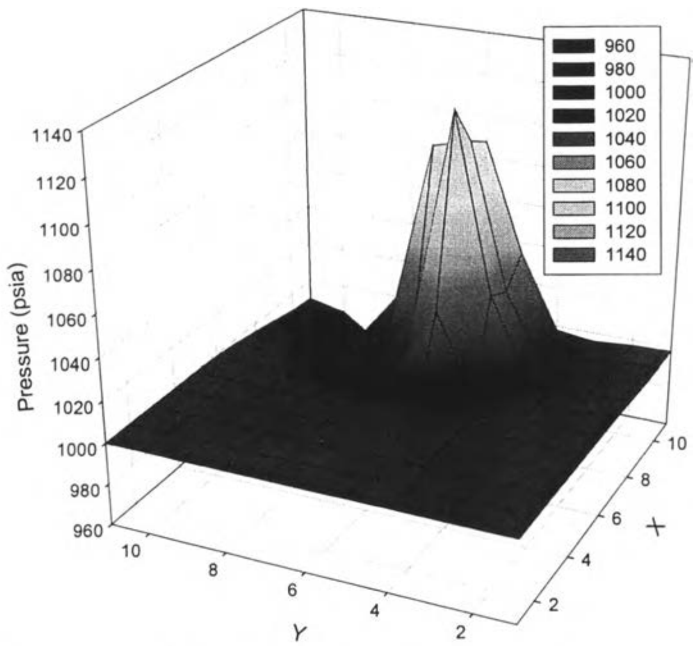


Figure 4.13 Pressure profile at T = 10 days.

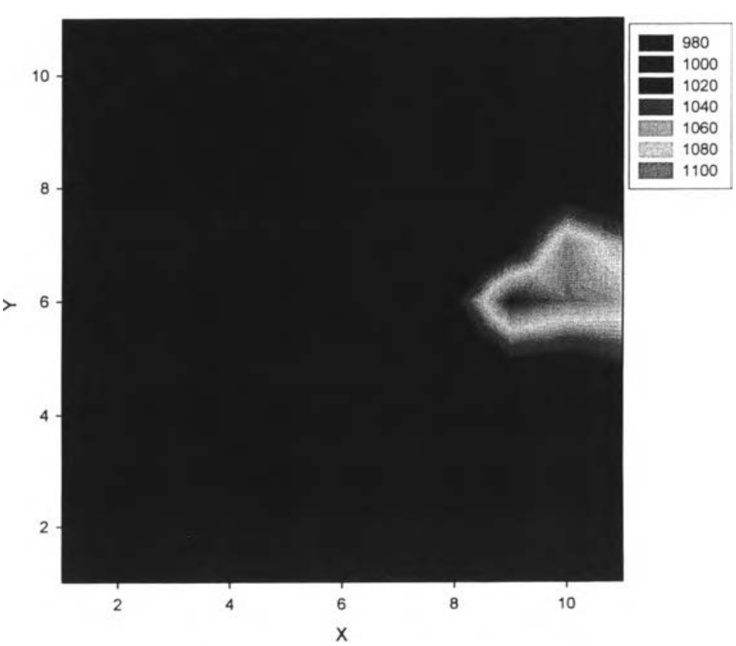


Figure 4.14 Cross sectional view of pressure profile at T = 10 days.

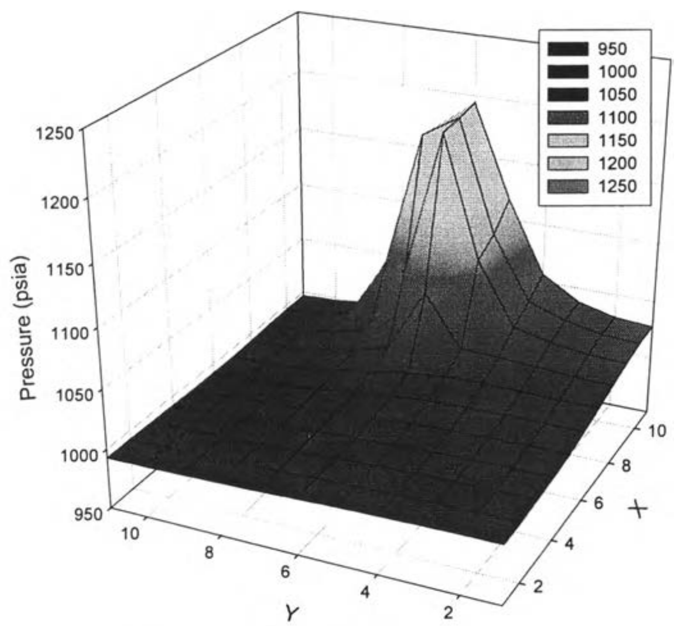


Figure 4.15 Pressure profile at T = 100 days.

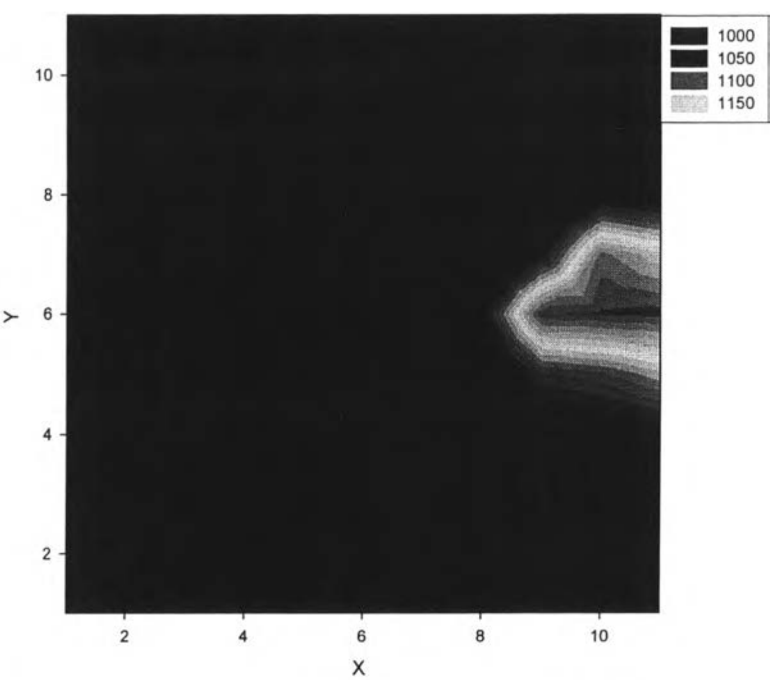


Figure 4.16 Cross sectional view of pressure profile at T = 100 days.

From case 2, the well is located at (x, y) = (8, 8). The pressure at well is lower than other pressure. It is similar as case 1, but the pressure at the well is more than some point that high permeability.

<u>Case 3</u>

For case 3, the well is located at low and unstable permeability reservoir. The result will be shown in Figure 4.17.

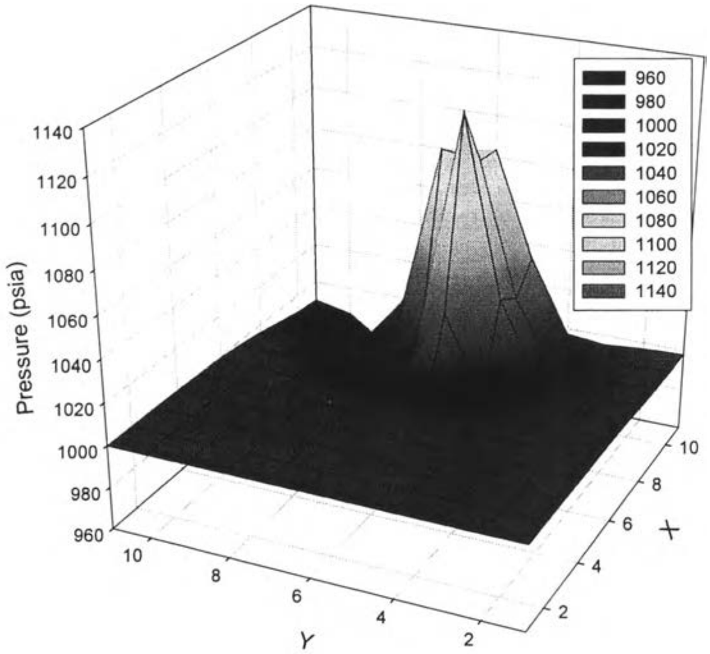


Figure 4.17 Pressure profile at T = 10 days.

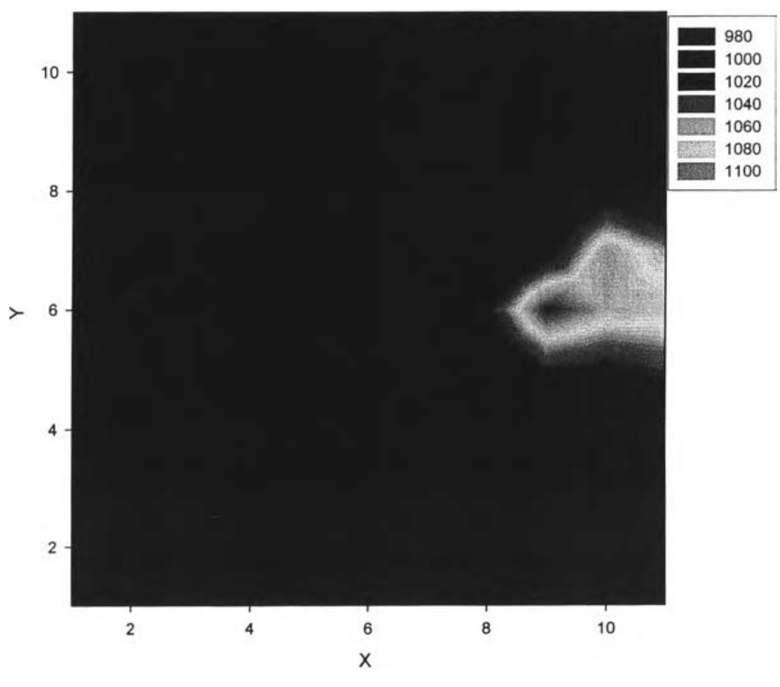


Figure 4.18 Cross sectional view of pressure profile at T = 10 days.

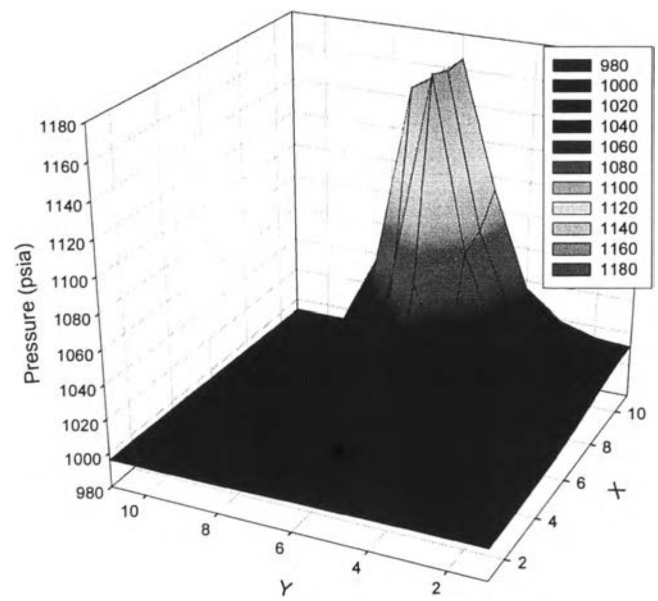


Figure 4.19 Pressure profile at T = 100 days.

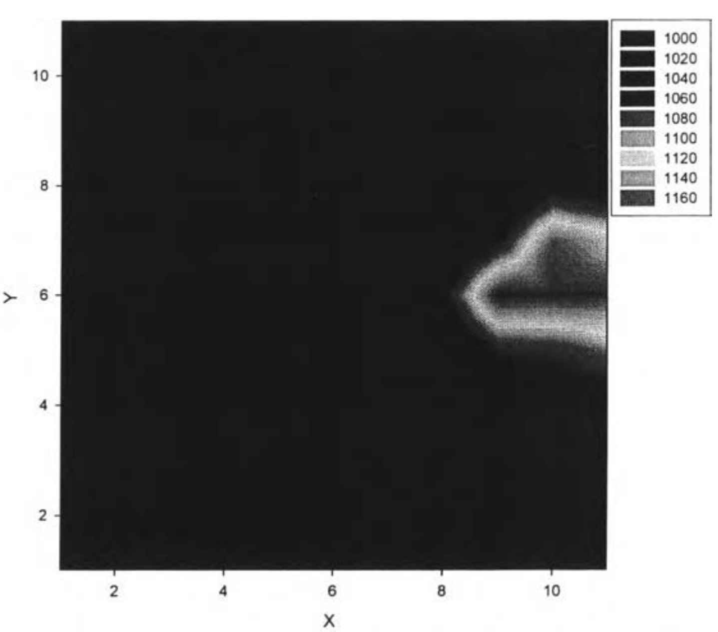


Figure 4.20 Cross section area of pressure profile at T = 100 days.

For case3, the well is located at grid point(x, y) = (10, 6) in the varied permeability reservoir. The result shows that the pressure at well is lower than surrounding pressure, but the well pressure is higher than points with high permeability.

4.4.2 Irregular Shape

Applied to the real case, the program is developed for general case.

4.4.2.1 Constant Permeability

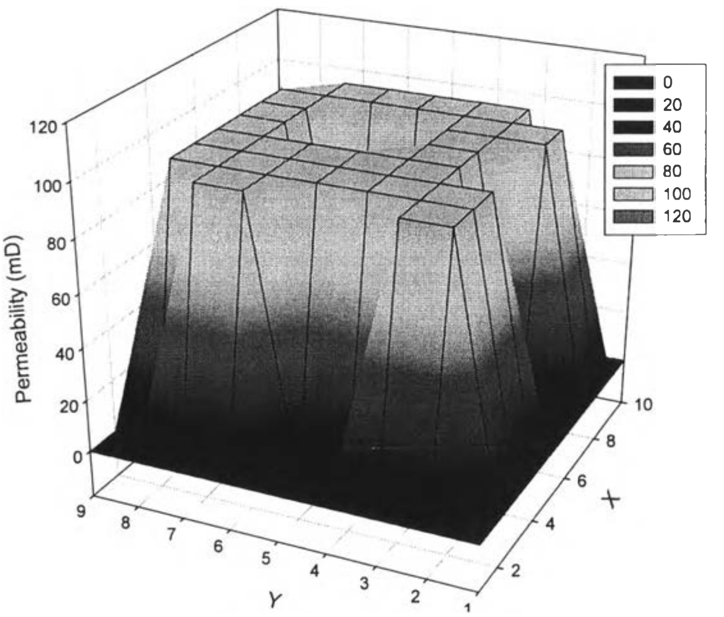


Figure 4.21 Permeability profile.

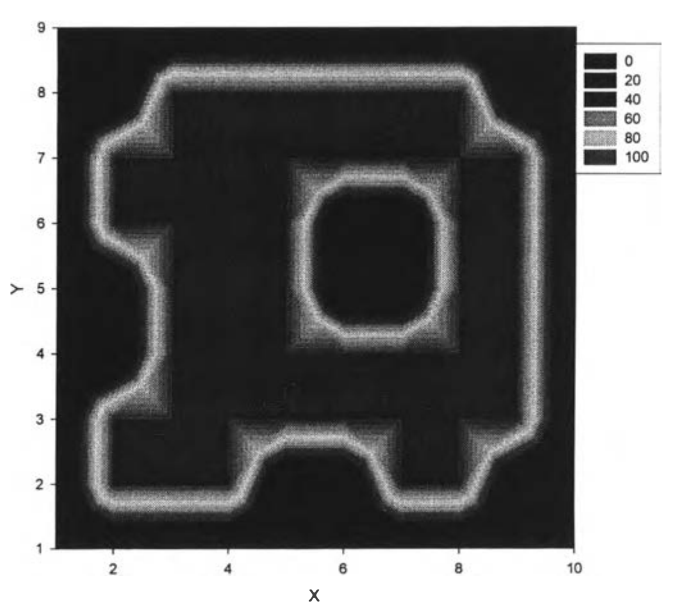


Figure 4.22 Cross sectional view of permeability profile.

From Figure4.21and Figure4.22, the model changes to irregular shape in constant permeability.

For case 1, the well is located at high and stable permeability. The result will be shown in Figure4.23 and Figure4.24.

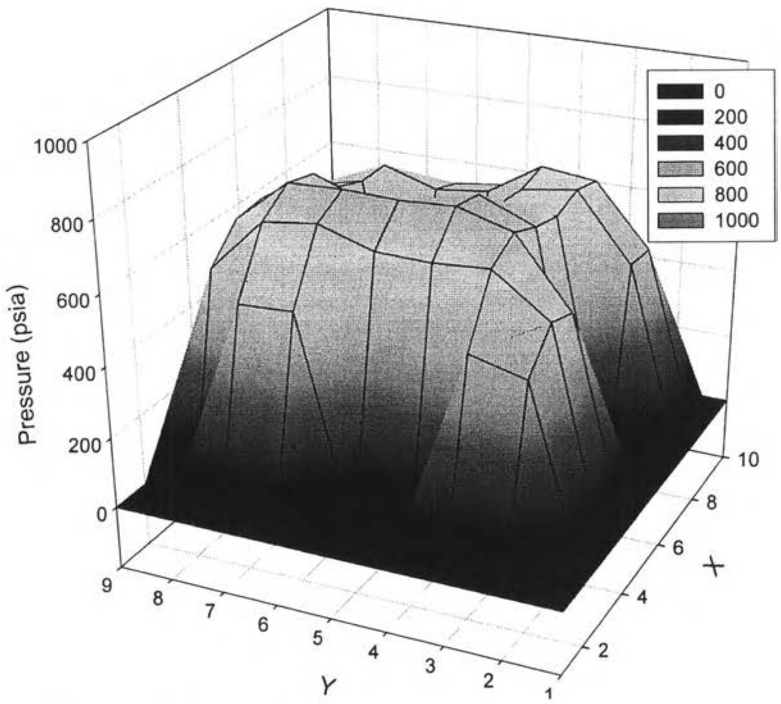


Figure 4.23 Pressure profile at T = 10 days.

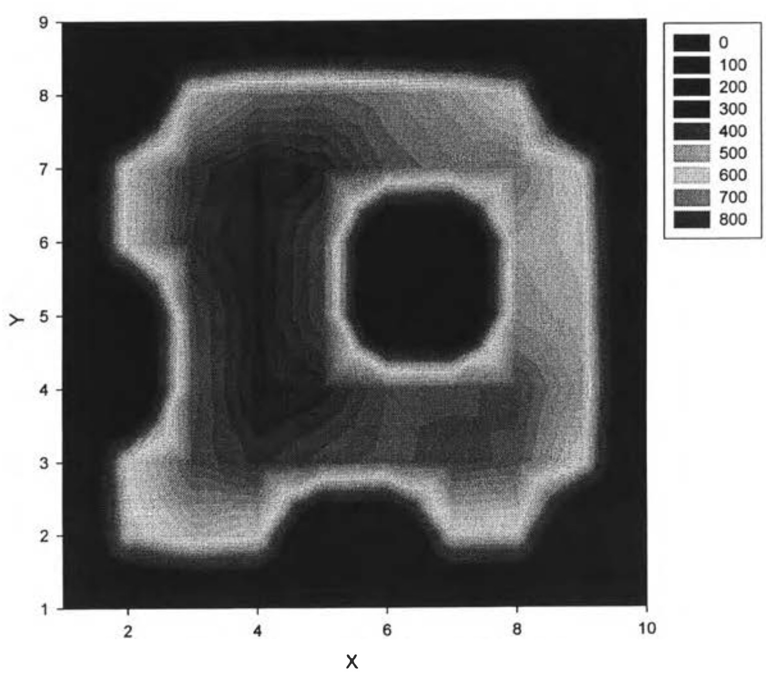


Figure 4.24 Cross sectional view of pressure profile at T = 10 days.

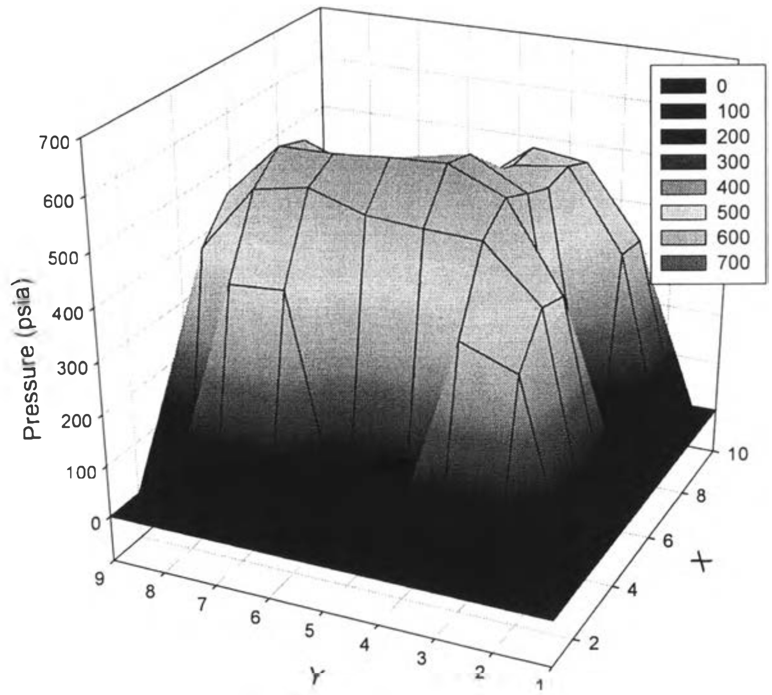


Figure 4.25 Pressure profile at T = 100 days.

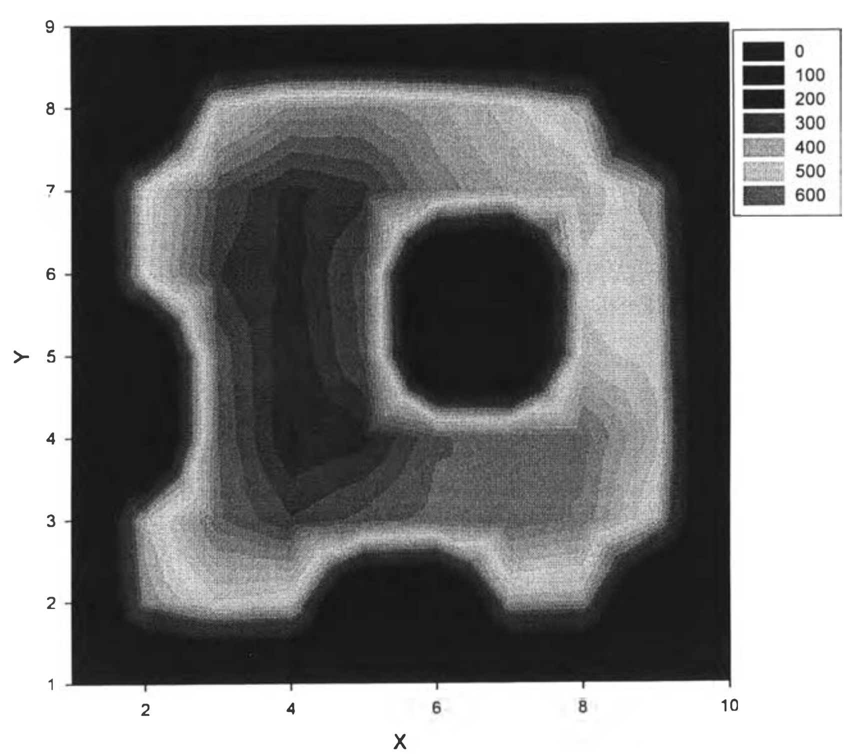


Figure 4.26 Cross sectional view of pressure profile at T = 100 days.

4.2.2.1 Inconstant Permeability

For the irregular shape, the program was applied to irregular shape reservoir with inconstant permeability. The result from the program is shown in Figure4.29.

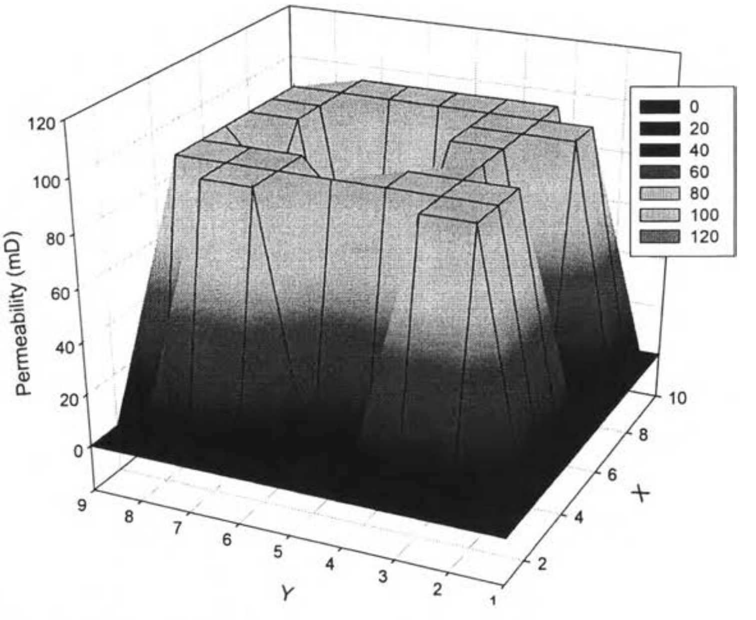


Figure 4.27 Permeability profile.

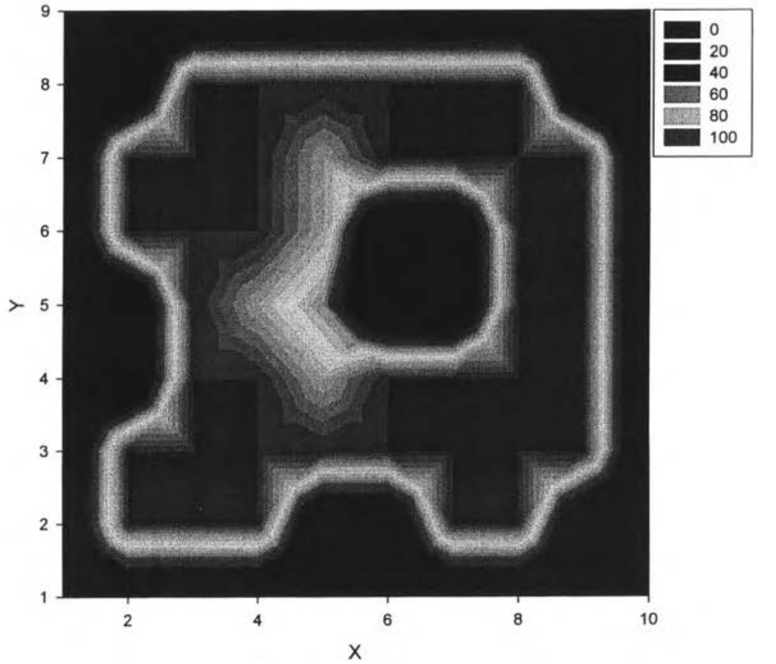


Figure 4.28 Cross sectional view of permeability profile.

The Figure 4.27 and Figure 4.28 show inconstant permeability profile of the reservoir.

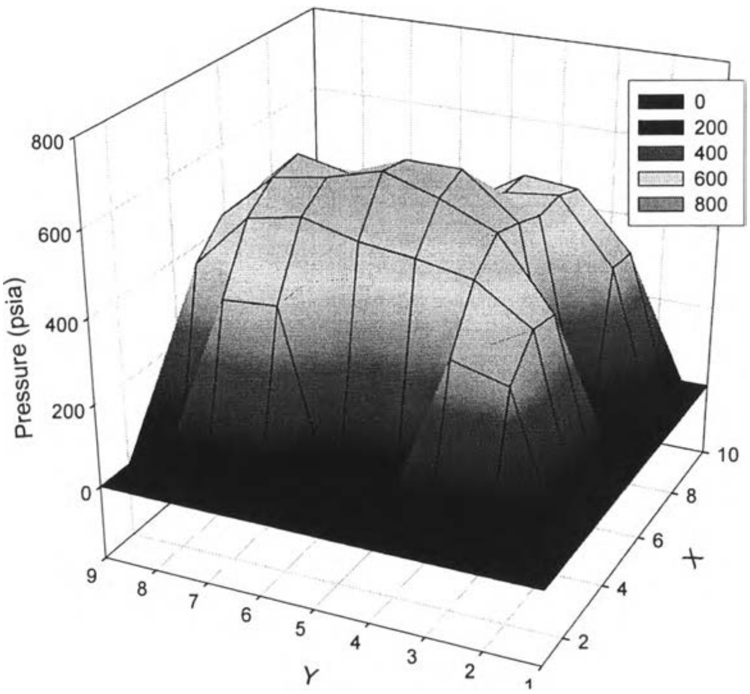


Figure 4.29 Pressure profile.

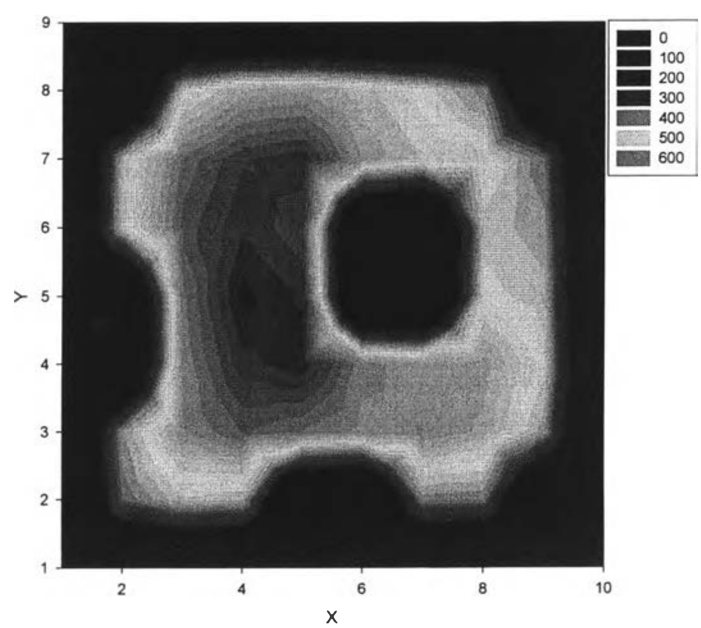


Figure 4.30 Cross sectional view of pressure profile.

When the time increase, the pressure profile near the well decreases as the similar as the old result.

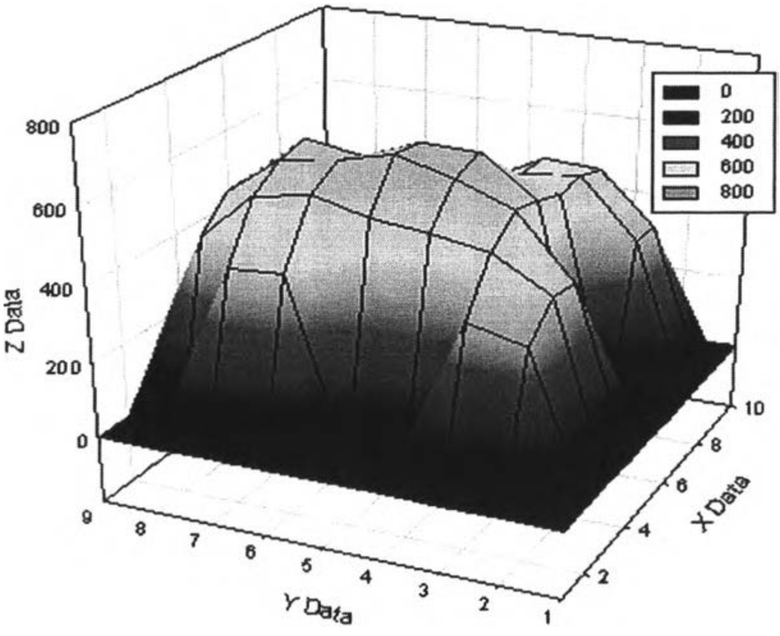


Figure 4.31 Pressure profile.

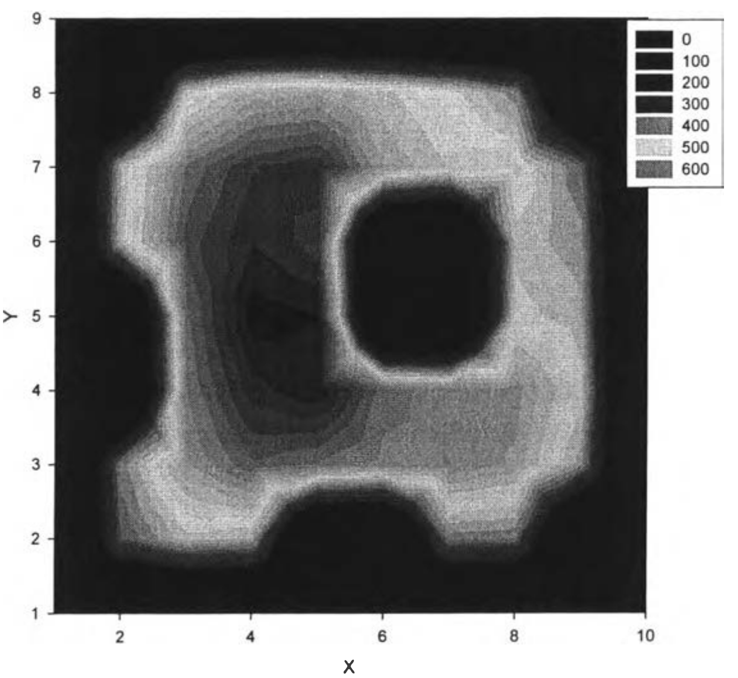


Figure 4.32 Cross sectional view of pressure profile.

When the time increase to 100 days, all the pressure profile decreases more than 10 days and the result is shown in Figure 4.33 and Figure 4.34.

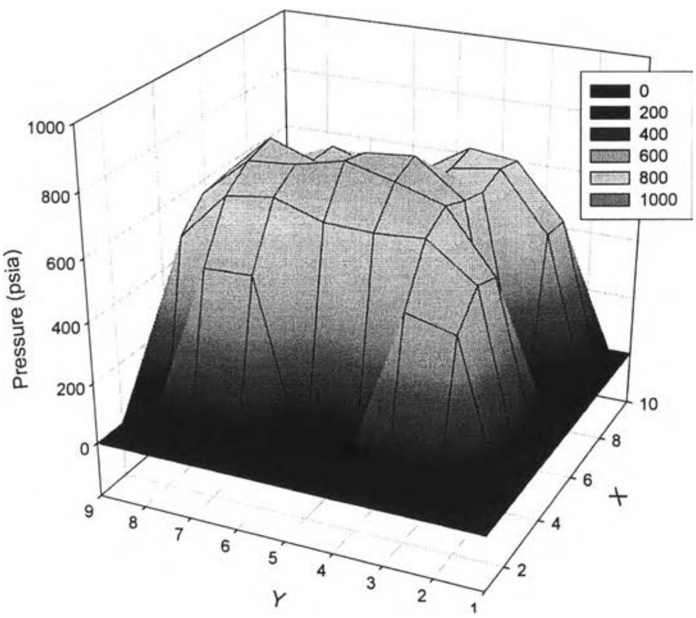


Figure 4.33 Pressure profile.

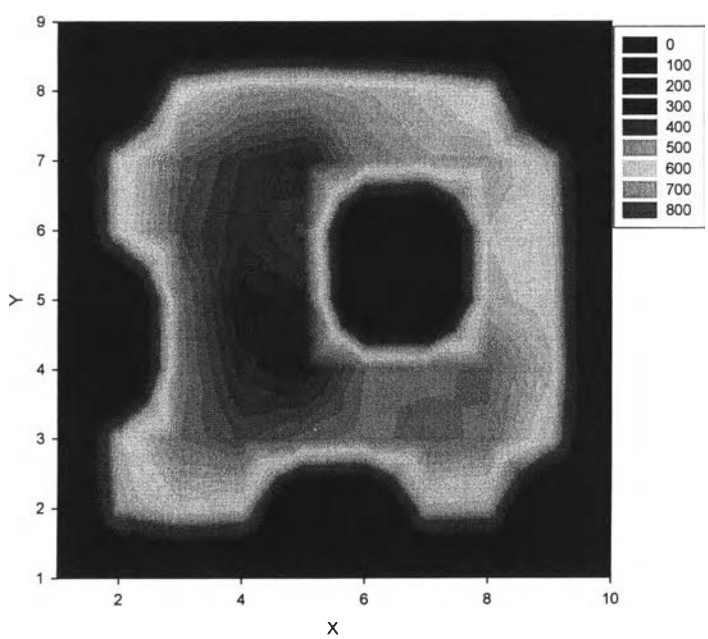


Figure 4.34 Cross sectional view of pressure profile.

4.3 Compare with difference grid point.

For finite difference analysis, I will apply it with regular reservoir that have 11 grid points in x and y direction shown in Figure 4.34.

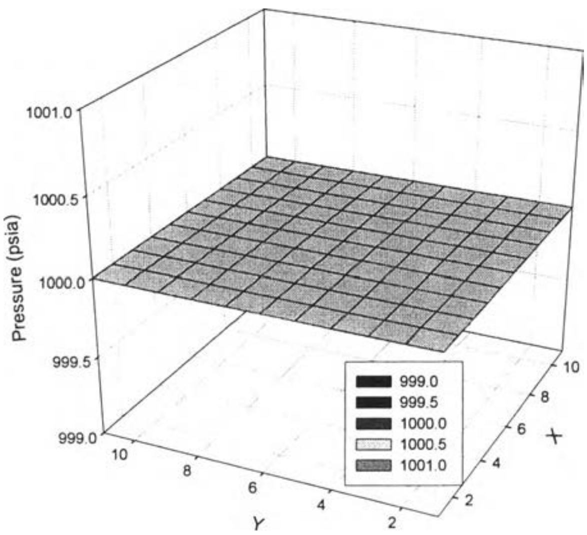
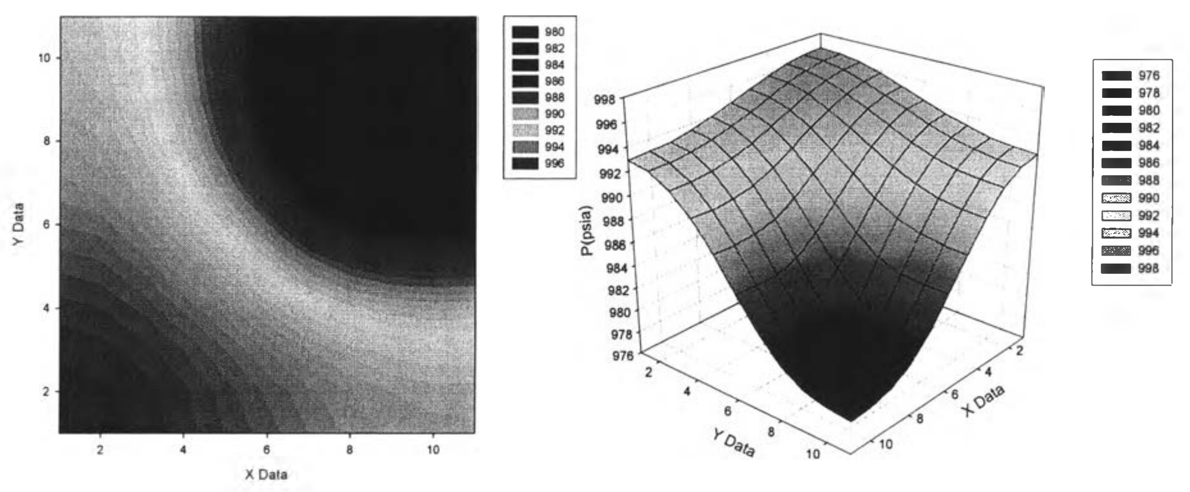


Figure 4.35 Initial pressure profile.

For development, I will drill the well at (8, 8). After operating for 100 days, the results are shown in Figure 4.36 (a) and (b).



(a) (b)

Figure 4.36 The pressure profile after 100 days.

For accuracy, the grid point will be added from an 11 by 11 to a 21 by 21. The initial pressure is shown in Figure 4.37.

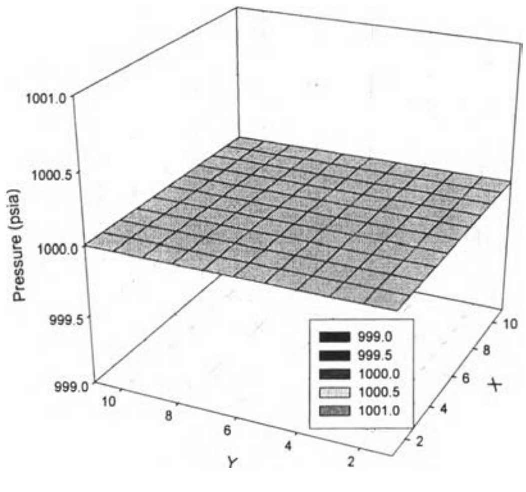
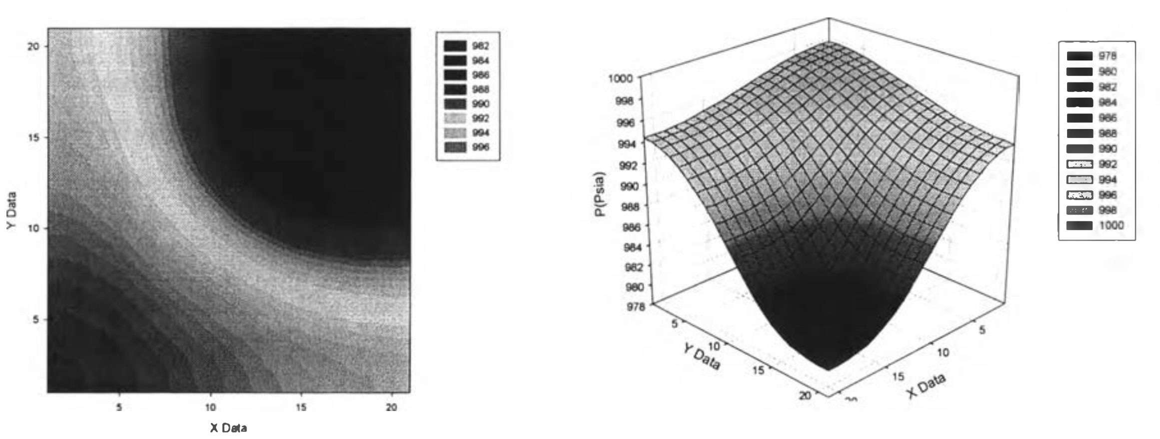


Figure 4.37 Initial pressure profile.

For adding the number of grid, the location of well will change to (14, 14). After operating for 100 days, the results are shown in Figure4 (a) and (b).



(a) (b)

Figure 4.38 The pressure profile after 100 days.

For comparing the added grid point, all results from an 11 by 11 are shown in Excel file 11, 11 and all results from a 21 by 21 are shown in Excel file 21, 21.Thered low represent the well location. The trend of pressure profile is the same, but the pressure at the well location is not the same because of the numerical error.

4.4 Multiple wells

For three wells, I will apply with regular reservoir that have 11 grid points in x and y direction shown in Figure 4.39.

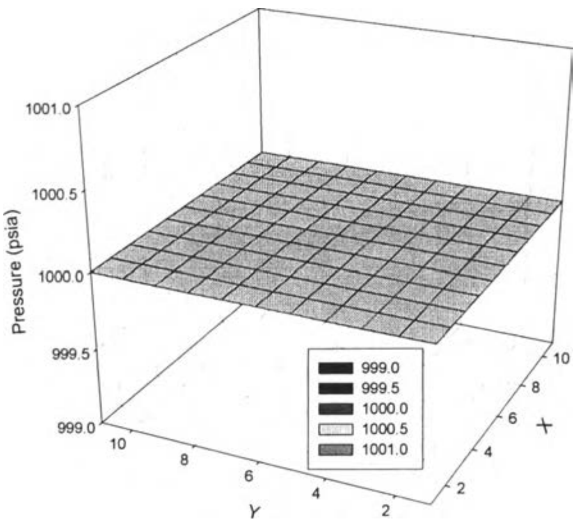


Figure 4.39 Initial pressure profile.

For development, the well is drilled at (4, 4) and (8, 8) and add the new well at (4, 8). After operating 40 days, the results are shown in Figure 4.40 (a) and (b).

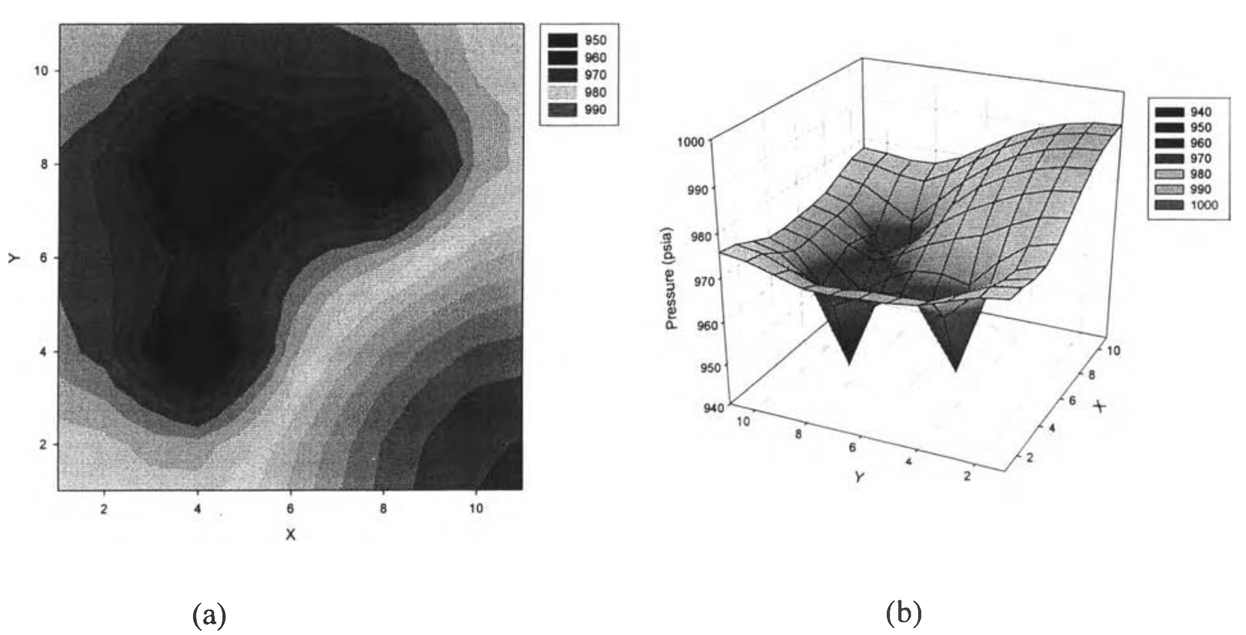


Figure 4.40 The pressure profile after 40 days.

For this case, the pressure at the well is the lowest and the natural gas can flow from the surrounding points that give reasonable and agree with the result before.

For accuracy, the grid point will be added from an 11 by 11 to a 21 by 21. The initial pressure is shown in Figure 4.41.

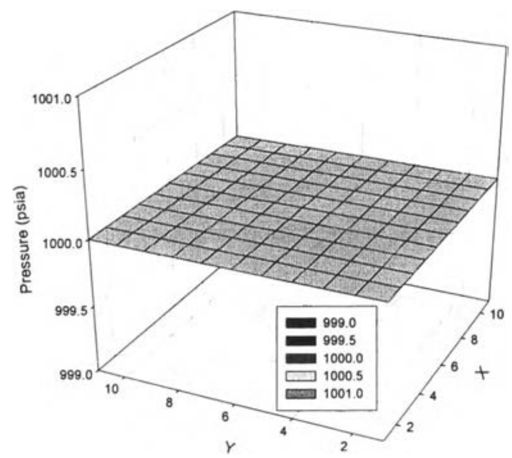
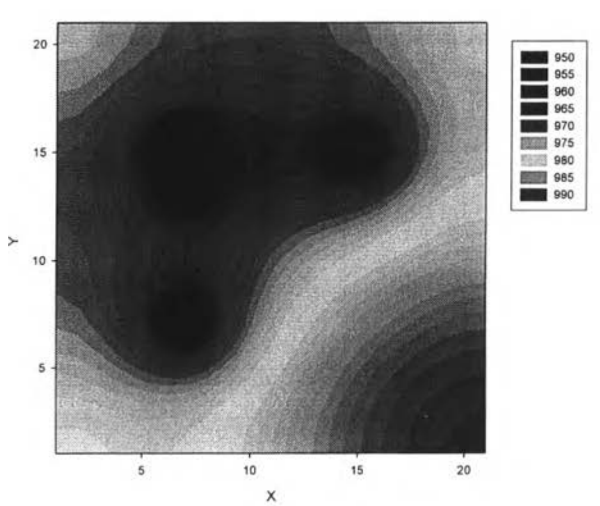
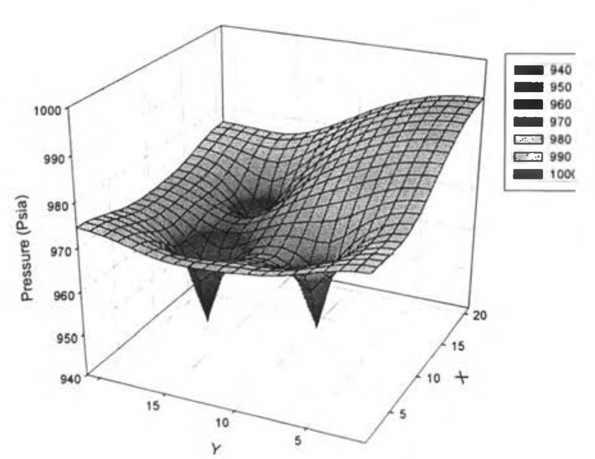


Figure 4.41 Initial pressure profile.

For add the number of grid, the location of well will be change to (7, 7) (7, 14) and (14, 14). After operating 40 days, the results are shown in Figure 4.42 (a) and (b).



(a)



(b)

Figure 4.42 The pressure profile after 40 days.

For comparing the added grid point, the results from a 21 by 21 is the same as an 11 by 11.May I explain you as follow: I will choose 3 points. For 11 by 11, the first point is the well position (8,8) at pressure Pwell, the second point is the surrounding near the well(7,7) at Psurr, and the last one(3,3) at Pfar far away from the well point. The (8, 8) drilled point, the plot of pressure VS time are shown in Figure 4.43.

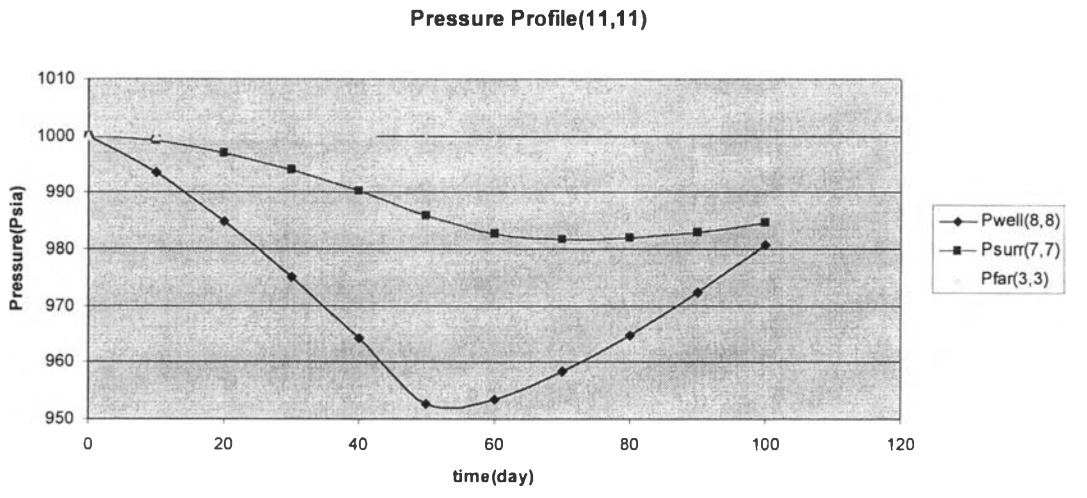


Figure 4.43 The pressure Profile of an 11, 11 grid reservoir.

For 21 by 21, the first point is the well position (14,14) that is the same as the point (8,8,) in an11,11 grid at pressure Pwell, the second point is the surrounding near the well(13,13) that is the same as the point (7,7) in an11,11 grid at Psurr, and the last one(4,4) that is the same as the point (3,3) in an11,11 grid at Pfar far away from the well point. The (14, 14) drilled point, the plot of pressure VS time are shown in Figure 4.44.

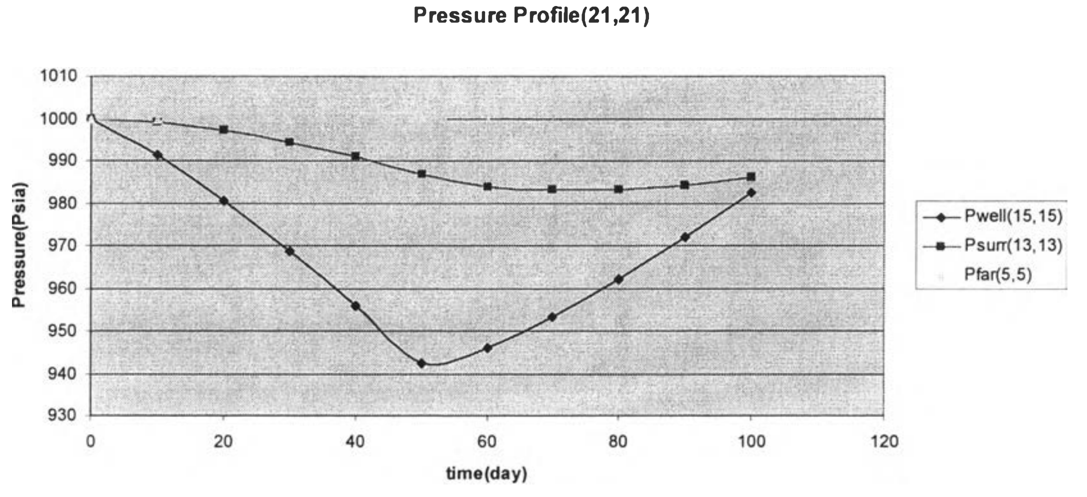


Figure 4.44 The pressure Profile of a 21, 21 grid reservoir.

For better understanding and seeing clearly, the result from an 11,11 and a 21,21 grid are shown in Figure 4.44.

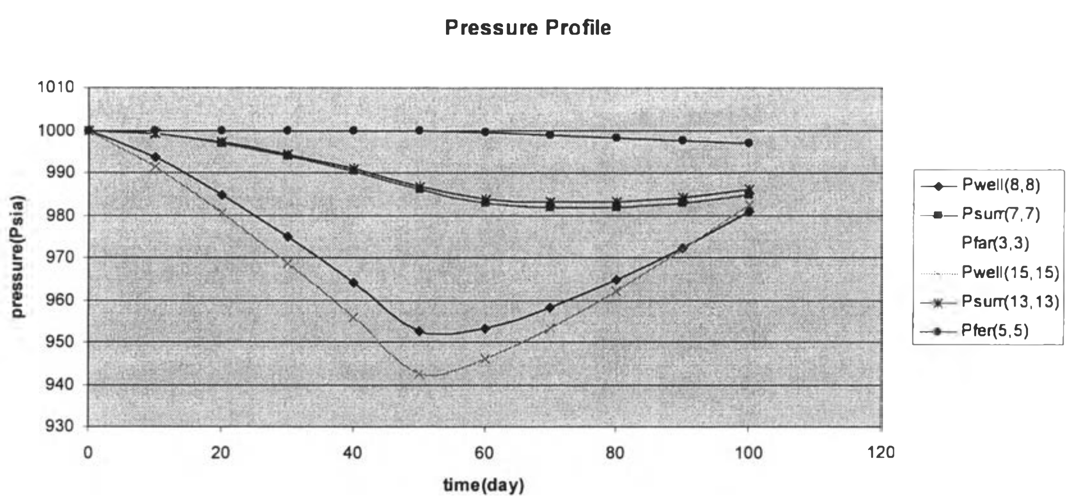


Figure 4.45 The pressure profile of reservoir.

For the comparison, the trends of pressure profile of an 11, 11 and a 21, 21 are the same. It is not equal, because the computer results are the approximate result having error of numerical error.

4.5 Physical property

The model starts with assumption which is the constant viscosity and compressibility factor. For more accurate, the model develops to real situation which is the constant viscosity and compressibility factor depend on pressure shown in equation (2.2)

$$\Phi = \int_{p_r}^{p} \frac{pdp}{z\mu} \tag{2.2}$$

Differentiate equation (2.2), it become.

$$d\Phi = \frac{p}{z\mu} dp \tag{4.1}$$

Rearrange the equation (4.1)

$$d\left(\frac{p^2}{2}\right) = z\mu d\Phi \tag{4.2}$$

And integrate equation (4.2), it become

$$p = \sqrt{\int 2z\mu d\Phi} \tag{4.3}$$

From equation (4.3), I plot $2z\mu$ as a function VS $d\Phi$. The pressure is the square root the area under the curve. For finding the area under curve, I use Trapezoidal rule to find it. From the Trapezoidal rule, the results are shown in Appendix D-1.

The second table is the relation between P and Φ.I will start with equation (2.2). From the equation (2.2), rearrange it and it become.

$$\Phi = \int \frac{1}{2z\mu} dp^2 \tag{4.4}$$

From equation (4.4), I will plot $\frac{1}{2z\mu}$ VS p^2. The results are shown in

Appendix D-2.

The two appendixes are applied to solve the problem of natural gas storage by the result in the table and compare with the result from independent u and z. For the comparesion, I select three point: the first point is the well position (8,8) at pressure Pwell, the second point is the surrounding near the well(7,7) at Psurr, and the last one(3,3) at Pfar far away from the well point. The grid points in comparesion are shown in Table 4.1.

Location of point	Symbol of Pressure	u and z independent from pressure(old)	u and z dependent from pressure(new)
Well	Pwell	8,8	8,8
Near well	Psurr	7,7	7,7
Far from well	Pfar	3,3	3,3

Table 4.1 The grid point in comparesion.

From the comparesion, the results are shown in Table 4.2 and Figure 4.46.

Total	u and z independent from pressure			u and z dependent from pressure		
t \ P	Pwell(8,8)	Psurr(7,7)	Pfar(3,3)	Pwell(8,8)	Psurr(7,7)	Pfar(3,3)
0	1000	1000	1000	1000	1000	1000
10	993.592	999.1849	1000	984.2427	995.3861	997.0154
20	984.8603	996.9815	999.9932	966.9703	990.9885	997.0018
30	975.006	993.9426	999.9458	947.6604	984.9393	996.9070
40	964.238	990.2463	999.8092	926.7823	977.6064	996.6339
50	952.6544	985.9747	999.5371	904.5815	969.1664	996.0900
60	953.4337	982.7372	999.0886	906.0666	962.7938	995.1938
70	958.2747	981.7076	998.4409	915.3197	960.7713	993.9000
80	964.7029	981.865	997.6271	927.6790	961.0803	992.2760
90	972.2894	982.8951	996.7139	942.3714	963.1039	990.4550
100	980.8301	984.6668	995.7695	959.0496	966.5893	988.5737

Table 4.2 The result of pressure from the natural gas storage program.

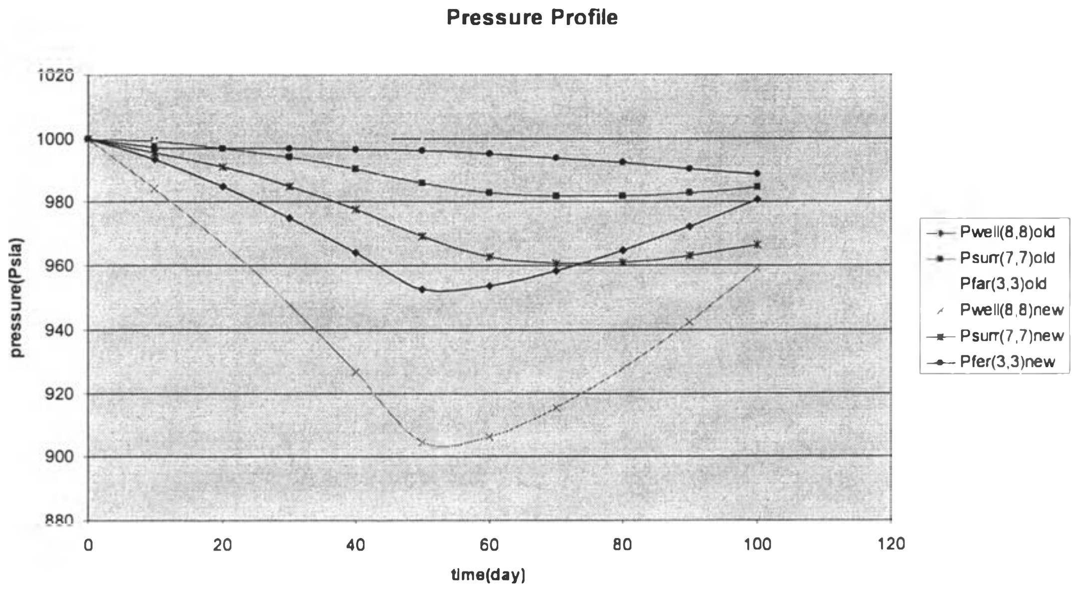


Figure 4.46 The result of pressure from the natural gas storage program.

The results of pressure profile from the natural gas storage program are the same trend.

4.6 Injection and withdrawal schedule.

For the injection and withdrawal schedule, I will plan to operate it into each year (about 12 months) with injection for eight months (240days) and withdrawal for four months (120days) because the study condition is the excess natural gas in the low demand season and supply in high demand season.

For this case, we start with injection the natural gas for 240 days by using the maximum injection rate 100 MMSCFD (Qmax) and the injection rate (Qs) that dependent with time. For the injection, I start with the pressure profile of reservoir at 100 psia. When the operate time at 240 day, it is the end of the injection the pressure profile of reservoir become 1000 psia and start with withdrawal by using the maximum withdrawal rate 200 MMSCFD (Qmax), After withdrawn the natural gas for 4 months, the pressure profile of reservoir become 100 psia. It is the same as the pressure profile before injection. The results are shown in Figure 1and the result data are shown in Table 4.3.

Time(day)	Qs(MMSCFD)
0	0
10	8.33
20	16.67
30	25
40	33.33
50	41.67
60	50
70	58.33
80	66.67
90	75

Time(day)	Qs(MMSCFD)
100	83.33
110	91.67
120	100
130	91.67
140	83.33
150	75
160	66.67
170	58.33
180	50
190	41.67

Time(day)	Qs(MMSCFD)
200	33.33
210	25
220	16.67
230	8.33
240	0
250	-33.33
260	-66.67
270	-100
280	-133.33
290	-166.67

Time(day)	Qs(MMSCFD)
300	-200
310	-166.67
320	-133.33
330	-100
340	-66.67
350	-33.33
360	0

Table 4.3 Injection and withdrawal data.

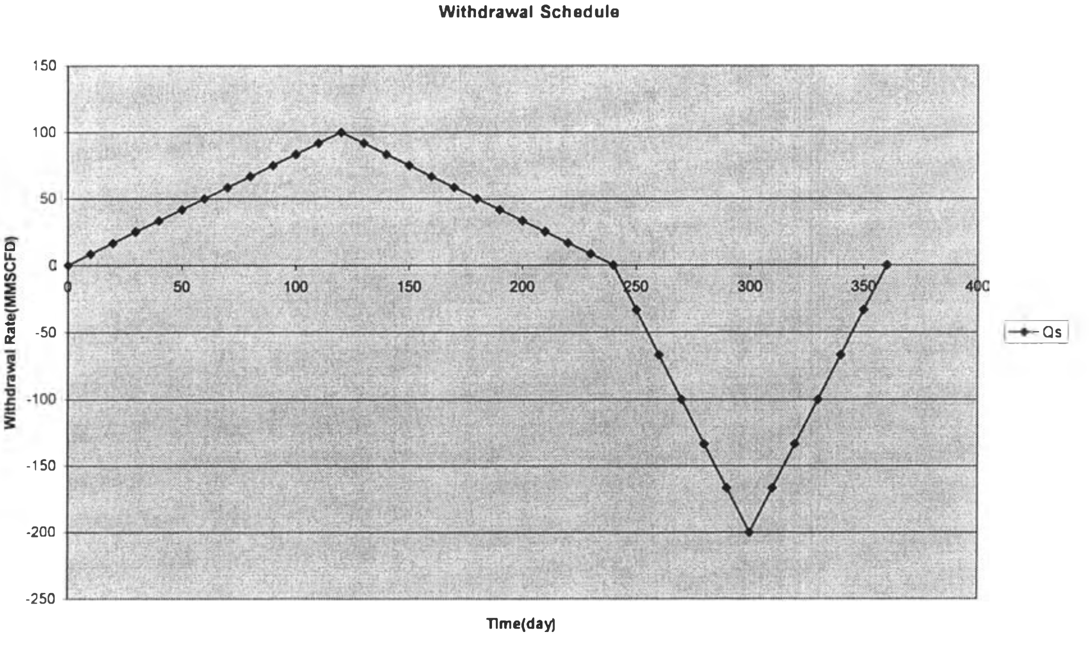


Figure 4.47 Injection and withdrawal schedule.

Note:

Qs is positive for injection rate

Qs is negative for withdrawal rate

4.7 Application

For applying the program to get the pressure distribution and gas production of the real reservoir, the first case is in carbonate reservoir. From this case, the program will predict the pressure profile at deepest layer.

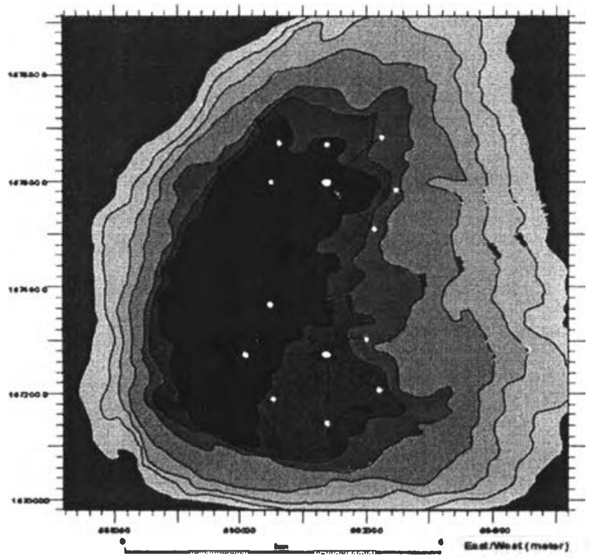


Figure 4.48 Carbonate reservoir.

From this case, the permeability of the reservoir is constant that is shown in Figure 4.49 and Figure 4.50.

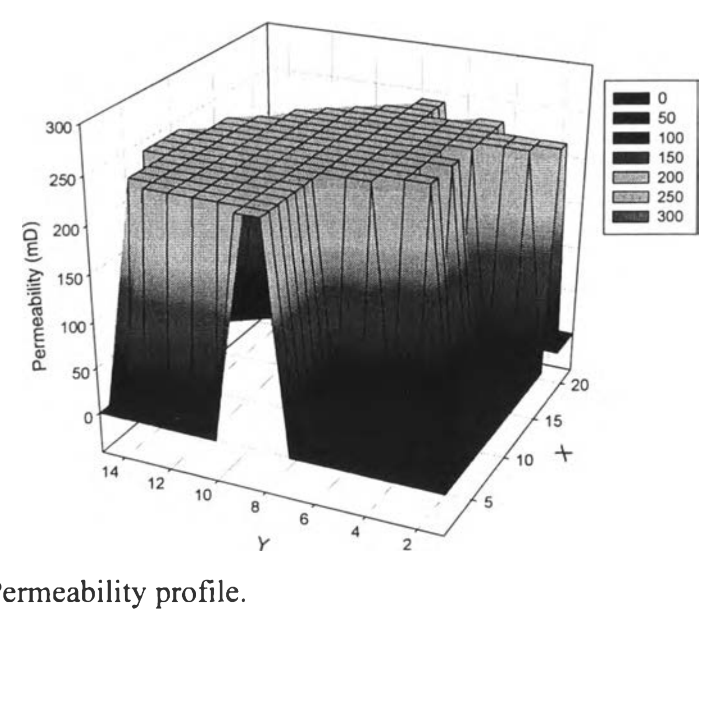


Figure 4.49 Permeability profile.

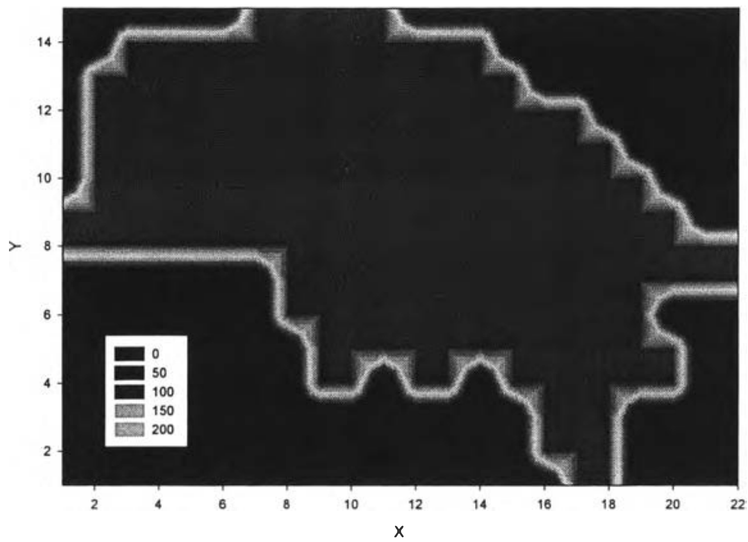


Figure 4.50 Cross sectional view of permeability profile.

For the pressure profile, it is low pressure near the well location which is agreement with the simulation case before and the results of pressure profile are shown in Figure 4.51 and Figure 4.52.

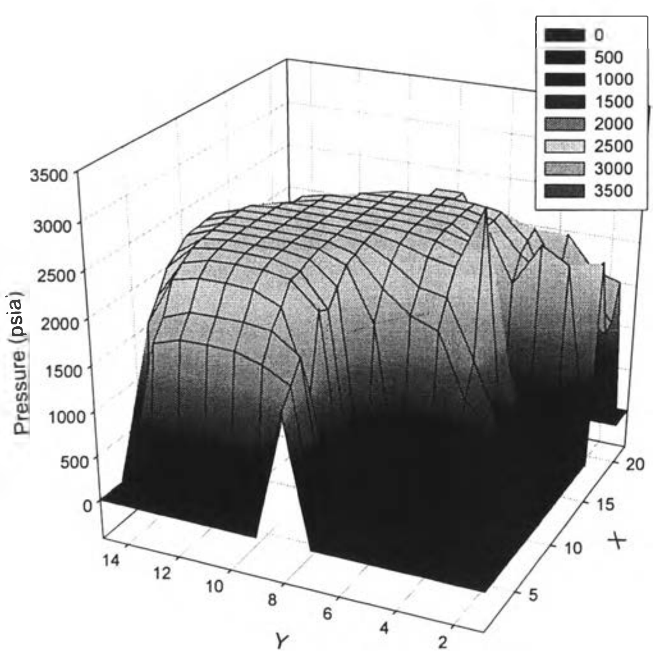


Figure 4.51 Pressure profile.

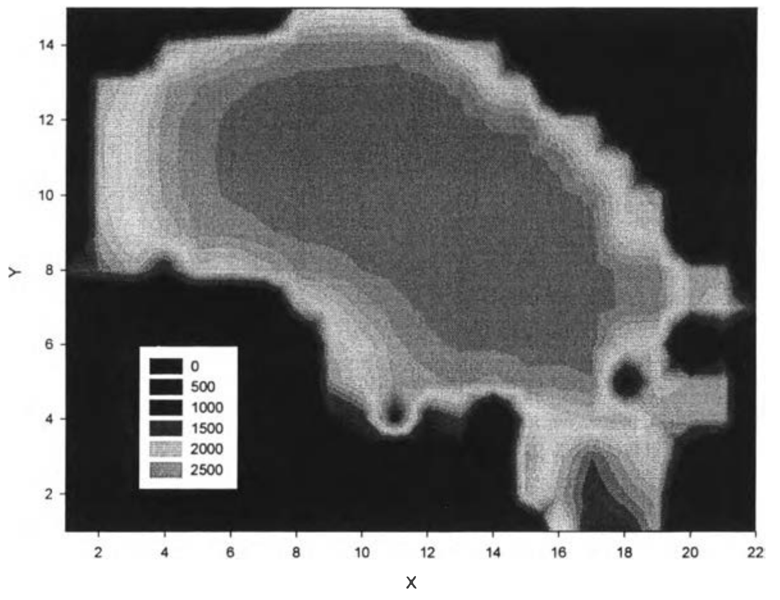


Figure 4.52 Cross sectional view of pressure profile.

The Figure 4.51 and Figure 4.52 are shown the pressure distribution at 10 days. The pressure profile decreases near the well that is agreement with other simulation result.