CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The two dimensional models of natural gas flowing in the reservoir have been developed. Two numerical methods, finite difference and finite element methods, have been chosen to solve the governing equation. Finite difference method uses ADI scheme to discretize the governing equation. The ADI scheme has been implemented in the FORTRAN program, For the finite element method, the commercial simulation software package called 'FEMLAB' is employed to solve the governing equation. The model can determine the relationship between flow rate and reservoir pressure with respect to time. The model results have shown that the flow can occur by the pressure gradient between the bottom well and reservoir. Then, the natural gas slightly flows from the reservoir to the well. Nevertheless, the results from these two methods are different. The finite difference method has some disadvantage, particularly, sizing of grid scale, time stepping and shape of reservoir. On the contrary, these drawbacks can be eliminated by the finite element method. From the relationship between cumulative withdrawn gas and average reservoir pressure in the real case as previously described, the emphasis of the finite element method is placed on investigating the pressure profile in reservoir.

5.2 Recommendations

Although the two-dimensional reservoir model can simulate the reservoir behaviors such as reservoir pressure, well pressure, top hole pressure and reservoir life time. But in realistic reservoir, the reservoir shape and gas behavior are more complicated than this work. At this point, several ways to achieve more accuracy model can be proposed as,

1. Extending governing equation to three-dimensional model.

The two dimensional mass balance equation (combining with Darcy's law) generates pressure profile in the rectangular coordinate as a function of time and space (x, y) as shown in Eq. (5-1).

$$\frac{\partial}{\partial x}\left(\frac{p}{ZT}\frac{hk}{\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{p}{ZT}\frac{hk}{\mu}\frac{\partial p}{\partial y}\right)-\frac{q_s p_s}{T_s}=\varepsilon h\frac{\partial(p/ZT)}{\partial t} \tag{5-1}$$

The three-dimensional governing equation can be applied from the previous equation, as shown below,

$$\frac{\partial}{\partial x}\left(\frac{p}{ZT}\frac{k}{\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{p}{ZT}\frac{k}{\mu}\frac{\partial p}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{p}{ZT}\frac{k}{\mu}\frac{\partial p}{\partial z}\right)-\frac{q_s p_s}{T_s}=\varepsilon\frac{\partial(p/ZT)}{\partial t} \tag{5-2}$$

The three-dimensional model can be studied on a small size of reservoir because of the limitation of commercial software, FEMLAB. In contrast, Gas behavior around the withdrawal well is investigated by this model. The reservoir size was assumed at 65×65×33 ft (139425 ft^3) and perforation at 6.5 ft long with diameter 1 ft as shown in Figure 5.1. The model with mesh process containing 6473 elements is depicted in Figure 5.2. The input data is also indicated in Table 4.3, except the reservoir size and withdrawal rate.

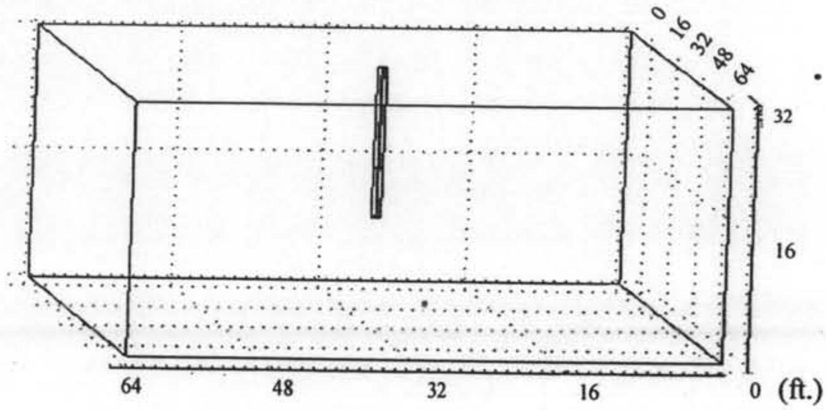

Figure 5.1 Geometry of regular shaped reservoir.

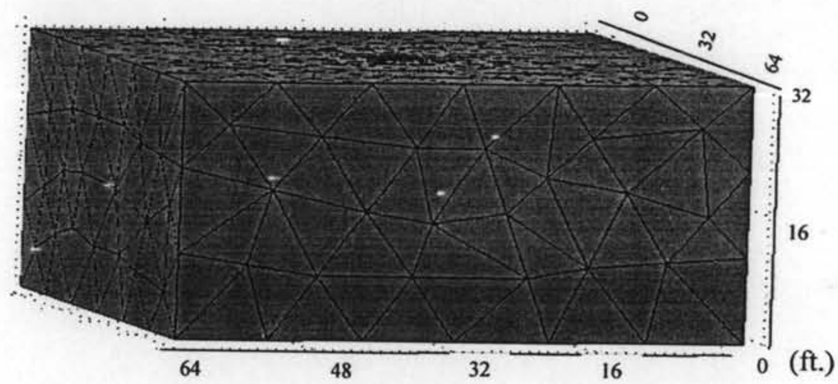

Figure 5.2 Elements on regular shaped reservoir.

The pressure profile with gas withdrawal (4000 SCFD) at location (10, 10 ft) is shown in Figure 5.3. It is observed that pressure profile gradually decreases at the withdrawal well. The stream lines (green line) represent the flow direction of fluid in the reservoir. Gas flows into the perforated area. This can be explained by the fact that the pressure gradient ($p_r > p_w$) around the bottom well causes natural gas flowing toward the withdrawal well.

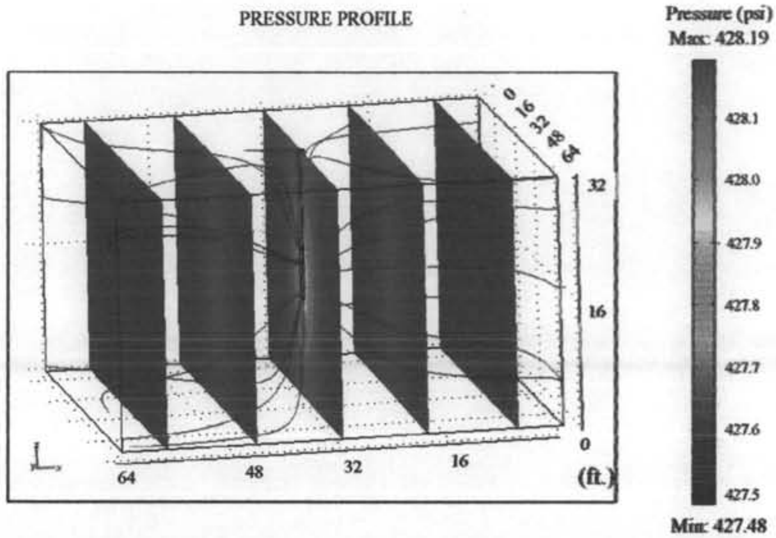

Figure 5.3 Pressure profile in regular shaped reservoir.

The pressure profiles after gas withdrawal (4000 SCFD) at location (10, 10 ft) is shown in Figure 5.4. The reservoir contains 2 layers, layer 1 is 65×65×23 ft (97175 ft^3) and layer 2 is 26×26×9.8 ft (6625 ft^3). The model contained 6222 elements. It is observed that the reservoir pressure in this case is lower than previous case (Figure 5.3) under the same withdrawal flow rate. This can be explained by the fact that the capacity of gas reservoir related to the volume of reservoir.

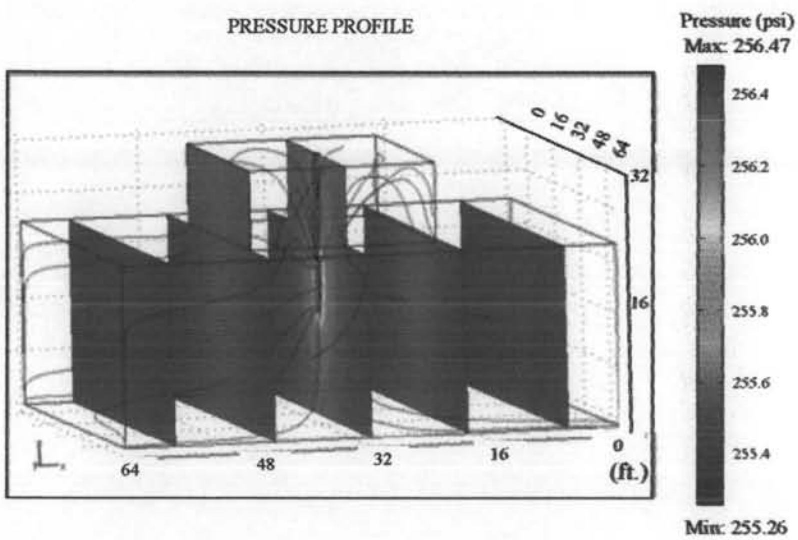

Figure 5.4 Pressure profile in 2-layer regular shaped reservoir.

For irregular shaped reservoir, the curved edge and interior islands are considered in this model as depicted in Figure 5.5. The model contained 5212 elements. The pressure profile with gas withdrawal (4000 SCFD) at location (10, 10 ft) is shown in Figure 5.6. The gas flows into the perforated area. As a result, the reservoir pressure in this case is lower than other cases under the same withdrawal flow rate because of the capacity of gas reservoir.

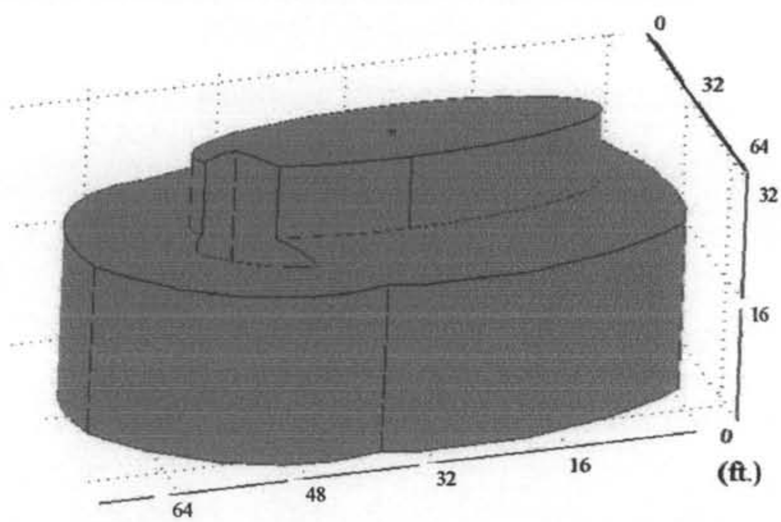

Figure 5.5 Geometry of irregular shaped reservoir.

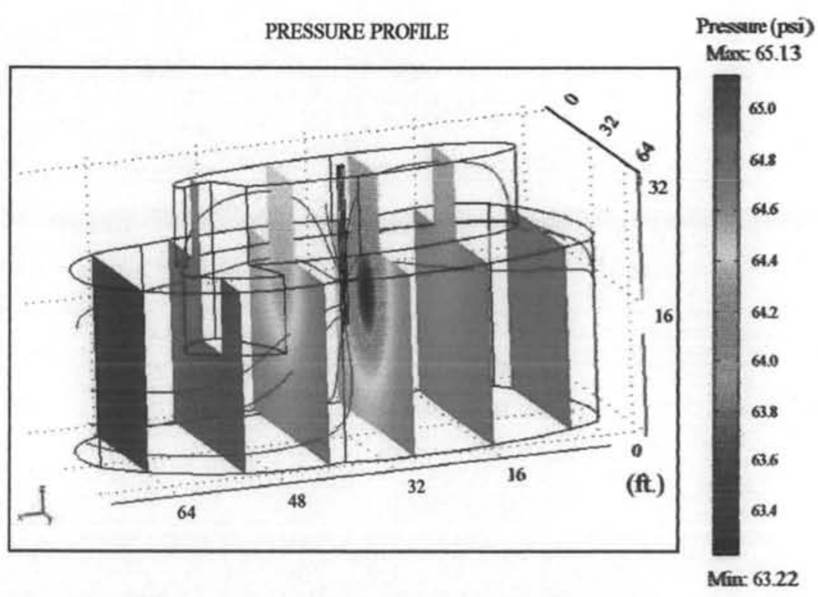

Figure 5.6 Pressure profile in 2-layer irregular shaped reservoir.

2. Applying the Peng-Robinson equation to represent actual gas behavior.

Peng-Robinson equation of state is used as the thermodynamic model to represent the relationship of gas density as a function of pressure and temperature, as shown below;

$$\nu^3 - (\frac{RT}{p} - b)\nu^2 + (\frac{a}{p} - \frac{2bRT}{p} - 3b^2)\nu - b(\frac{a}{p} - \frac{bRT}{p} - b^2) = 0 \qquad (5\text{-}3)$$

where, $a = a_c\alpha$, $a_c = 0.457235(RTc)^2/Pc$, $b = 0.077796*R*Tc/Pc$, $\alpha^{1/2} = 1+(0.37646 +1.54226\omega - 0.26992\omega^2)(1-\sqrt{Tr})$, ω acentric factor, p is pressure (atm), Pc critical pressure (atm), R gas constant (82.053 atm cm^3 /mol K), T temperature (K), Tc critical Temperature (K), Tr reduced temperature (T/Tc), ν molar volume, Mw/ρ, (cm^3 /mol).

In realistic reservoir, real gas is approximated to be ideal at low pressure. At high pressure, the intermolecular forces between hydrocarbon molecules are significant, the ideal gas behavior can not be assumed for real gas. Peng-Robinson equation is used for describing the real gas behaviors instead of ideal gas law, as depicted in Figure 5.7.

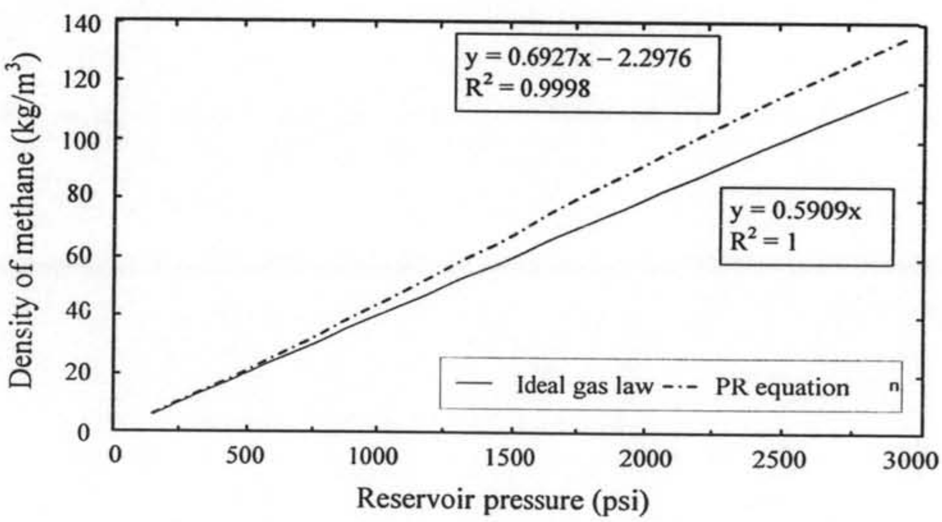

Figure 5.7 Relationship between density of gas and reservoir pressure at 330 K.