CHAPTER IX

CONCLUSIONS

This study is intended to investigate the validity of the material balance or the p/z plot method when applied to single- and multi-layered gas reservoirs. All investigations in this study are based on the assumption that the studied reservoirs are volumetric dry gas reservoirs. Not only the applicability of the p/z plot method but also the applicability of the pseudo-steady state equation (PSSE) in estimating $\bar{p}$ is investigated. A reservoir simulator was used in the study to generate $\bar{p}$ and other parameters needed for generating a p/z plot. All the obtained parameters (including GIIP and reserves) from the simulator were considered as actual values. In this study, $\bar{p}$ is also generated from the pseudo-steady state equation which is generally used in practice. Both $\bar{p}$'s obtained from the two different sources were used in generating p/z plots.

From the study of a single-layered reservoir with one production well, shapes of p/z plots of all cases studied can be catagorized to be a straight line and a concave-upward curve. It is found that when using $\bar{p}$ obtained from the simulator (actual $\bar{p}$) generating a p/z plot, the obtained p/z plot always shows a straight line. But, when using $\bar{p}$ from the PSSE, in some cases, the obtained p/z plot shows a concave-upward curve. The appearance of a straight-line p/z plot for all studied cases where using $\bar{p}$ from a simulator or actual $\bar{p}$ implies that the material balance method can be applied to any volumetric dry gas reservoir and the resulting GIIP will be equal or very close to the actual value provided that actual $\bar{p}$'s are used. Concave-upward p/z plots found in some cases where $\bar{p}$'s from the PSSE are used imply that some parameters have effects on calculated $\bar{p}$ from the PSSE, hence a p/z plot. A concave-upward p/z plot causes more deviation of resulting GIIP from actual value than that obtained from a straight-line p/z plot. Effects of parameters involved in the PSSE were investigated. From the study, it is found that permeability, gas flow rate, and skin factor have effects on the deviations of calculated $\bar{p}$ (from the PSSE) and resulting GIIP (for cases that p/z plots are generated from $\bar{p}$'s from the PSSE) from actual values. More deviations of calculated $\bar{p}$ and resulting GIIP were observed when permeability is low and gas flow rate is high, and/or skin factor is high. Other parameters which are porosity, thickness, gas gravity, and impurities have insignificant effects on the deviations of calculated $\bar{p}$ and resulting GIIP from actual values. After studying effects of all these parameters, the p/z plot method was applied to a single-layered reservoir with two production wells. From the study, it is found that for the case of a single-layered reservoir with two wells where the two wells produce at constant rates, both separated-well and combined-well methods can be used with acceptable errors.

For a two-layered reservoir with one production well, flow rate allocation to each layer was investigated. A flow-rate allocation equation for a two-layered reservoir with one well was generated. This equation works well when total flow rate is low. At higher total gas rate, the use of this equation causes high errors in estimating allocated flow rate of each layer. Conclusions from the flow-rate allocation study are: (1) pore volume of each layer seems to have more influence on flow rate allocation than permeability, (2) at high rate, the influence of pore volume seems to decrease while that of permeability seems to increase, and (3) at low rate, influence of permeability can be considered as negligible and the rate allocation can be considered to be solely influenced by pore volume of each layer. After the study of flow rate allocation, separated-layer and combined-layer methods were studied and applied to a two-layered reservoir with one well. From the study, it is found that if rate allocation could be applied to any system of a two-layered reservoir with one well, both separated-layer and combined-layer methods can also be applied to that system with acceptable errors.

For a two-layered reservoir with two wells, if each of the two wells penetrates both of the two layers provided that rate allocation can be applied, both separated-layer and combined-layer methods can be applied. For such a case, if flow rates of the two wells are constant, both separated-well and combined-well methods can also be applied. Application of the four methods (separated-layer and separated-well, separated-layer and combined-well, combined-layer and separated-well, and combined-layer and combined-well methods) for such a case will yield the same range of acceptable errors of resulting GIIP's. If one of two wells in a two-layers-and-two-wells system penetrates only one layer (while the other penetrates both layers), only the combined-layer and combined-well method is suggested to be used.

For a three-layered reservoir with one well where all layers have the same rock and fluid properties, both separated-layer and combined-layer methods can be applied with acceptable errors.

When the material balance method is applied to real data, another interesting point can be concluded as follows. For a multi-layered reservoir with one well where CO_2 of each layer is known and the average CO_2 of the total gas produced is approximately constant, by assuming that CO_2 of each layer is constant for the whole production period, estimated GIIP of any layer in the system can be obtained from a product of known estimated GIIP of the whole system and the proportion of the CO_2 of that layer to the average CO_2 of the total gas produced based on volume averaging.