CHAPTER VII

TWO- AND THREE-LAYERED RESERVOIRS

For a two-layered reservoir, calculation of GIIP can be performed in two ways, calculating GIIP for each layer separately (separated-layer method) and calculating GIIP only for the whole system (both layers)(combined-layer method). In the separated-layer method, GIIP of each layer will be calculated separately. The total GIIP for the system will be the summation of the GIIP of the two layers. To obtain GIIP for each layer, flow rate and $\bar{p}$ of each layer must be known, in addition to rock and fluid properties and related conditions.

Using the combined-layer method, average rock and fluid properties and related conditions based on rock and fluid properties and related conditions of each layer must be estimated for using in the calculation of $\bar{p}$ for the combined system. Then, $\bar{p}$ can be used to construct the p/z plot, and GIIP can be estimated.

Before discussing about the two methods of estimating GIIP for a two-layered reservoir, the allocation of flow rate for each layer will be discussed next.

7.1 Rate allocation

Due to the need for flow rate for each layer in the separated method of estimating GIIP, it is necessary to allocate rate to each layer, knowing the total rate, if there is no production survey to measure flow rate of each layer.

In order to allocate flow rate to each layer, a reservoir simulation run was performed to see if flow rate for each layer can be allocated based on the kh value of each layer.

Figure 7-1 shows the results of the run. It is surprising to see that flow rate for each layer is not constant though the total flow rate is constant (over some period) and does not follow the kh allocation concept that has been widely used. It was thought, then, that detailed investigation on flow rate allocation for a two-layered system was necessary.

However, before conducting such investigation, analysis of the flow rate curve characteristics (Figure 7-1) and assumptions necessary for flow rate allocation should be discussed.

The reservoir system for flow rate profiles in Figure 7-1 is a two-layered system with following different properties: k_1 =100 md, k_2 = 20 md, ϕ_1 = 0.1, ϕ_2 = 0.3, h_1 = 30 ft, and h_2 = 15 ft, where subscript 1 refers to layer 1 or the upper layer and subscript 2 refers to layer 2 or the lower layer. These two layers are produced through one well located at the center of each layer at a total rate of 5 MMscf/d. Other properties and conditions can be found in Chapter V. With these properties, the ratios of kh of each layer to total kh are 0.909 for layer 1 and 0.091 for layer 2. Therefore, based on kh allocation concept, flow rate for layer 1 (q_1) should be 4.545 MMscf/d and flow rate for layer 2 (q_2) should be 0.455 MMscf/d.

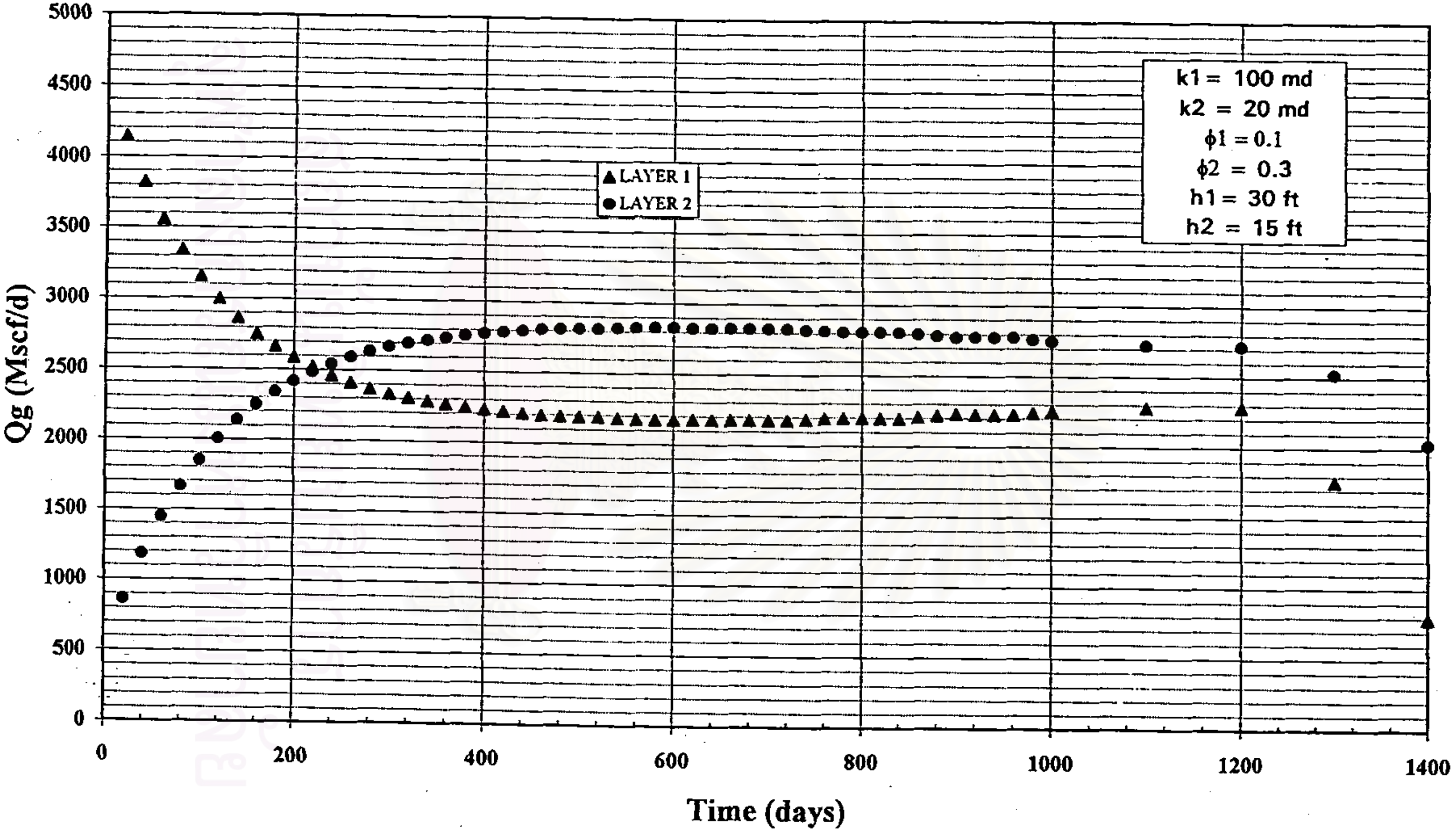

Figure 7-1 Flow rate of each layer for a typical two-layered reservoir

In Figure 7-1, it seems that only at the start of production that the rate of layer 1 is equal to 4.545 MMscf/d and the rate of layer 2 is equal to 0.455 MMscf/d. Later, the rate of layer 1 decreases while the rate of layer 2 increases. At some later point in time, the rate of layer1 slightly decreases again. Up to even some later point in time, both rates will decrease and the total rate cannot be maintained at 5 MMscf/d. That is, the reservoir pressure depletes to the point that the reservoir cannot maintain 5-MMscf/d rate and it produces at lower rate.

Though flow rates of both layers are not constant, there is a period of time that both rates are almost constant (about between 400 - 1000 days). Two constant-rate lines which are approximately fitted to the data points in this period will be drawn and treated as constant flow rates for the two layers. And in order to be able to use the pseudo-steady state equation from early time, the rate of each layer will be assumed to be constant since the start of production.

Looking at the two curves in Figure 7-1, one can see that the rates of both layers vary from the beginning up to 400 days, after that both rates are almost constant.

Other combinations of k, ϕ, h, and A were assigned to the two-layered reservoir systems which produced at various rates. The plots of q_1 and q_2 vs. time show behaviors similar to those shown in Figure 7-1. From the resulting q_1 and q_2 vs. time of the combinations, the relationship of q_1 and q_2 to k, ϕ, h, and A was investigated. It was hypothesized that the relationship can be written by:

$$\frac{q_2}{q_1} = (\frac{A_2}{A_1})^a (\frac{h_2}{h_1})^b (\frac{\phi_2}{\phi_1})^c (\frac{k_2}{k_1})^d \qquad (7\text{-}1)$$

where ,

q_1 = gas flow rate of layer 1, MMscf/d

q_2 = gas flow rate of layer 2, MMscf/d

A_1 = drainage area of layer 1, ft^2

A_2 = drainage area of layer 2, ft^2

h_1 = thickness of layer 1, ft

h_2 = thickness of layer 2, ft

ϕ_1 = porosity of layer 1, fraction

ϕ_2 = porosity of layer 2, fraction

k_1 = permeability of layer 1, md

k_2 = permeability of layer 2, md

a, b, c, d = exponential constants

Using Equation 7-1 and the results of various runs (Appendix B: details of used parameters of all cases run, Appendix C: examples of plots of cases run), a, b, c, and d can be estimated as shown in Table 7-1. These exponential constants were obtained through use of least squared. Earlier, it was thought that universal exponential constants can be obtained for used at any gas flow rates. Such attempt failed and exponential constants for each specific rate were obtained. In Table 7-1, ranges of values of $\frac{A_2}{A_1}$, $\frac{h_2}{h_1}$, $\frac{\phi_2}{\phi_1}$, and $\frac{k_2}{k_1}$ are also given so that it is known when these

Table 7-1 Estimates of exponential constants

Qg (MMscf/d)	Ranges of the Parameters				a	b	c	d	Range of Error
	A2/A1	h2/h1	$\phi 2/\phi 1$	k2/k1					
1	0.4 to 2.5	0.5 to 2.0	0.3 to 3.0	0.1 to 10	0.9979	1.0050	0.9945	0.0089	-2.9 % to + 1.5 %
5	0.4 to 2.5	0.5 to 2.0	0.3 to 3.0	0.1 to 10	0.9618	1.0198	0.9566	0.0499	-6.4 % to +2.8 %
10	0.4 to 2.5	0.5 to 2.0	0.3 to 3.0	0.1 to 10	0.8482	0.9685	0.8856	0.1115	-10.4 % to +8.6 %
15	0.4 to 2.5	0.5 to 2.0	0.3 to 3.0	0.1 to 10	n/a	n/a	n/a	n/a	more than 50 % error
20	0.4 to 2.5	0.5 to 2.0	0.3 to 3.0	0.1 to 10	n/a	n/a	n/a	n/a	more than 50 % error

exponential constants can be applied. In addition, ranges of errors when using these exponential constants to calculate $\frac{q_2}{q_1}$ are also shown. From these error values, it may be said that the exponential constants for gas flow rate of 10, 15, and 20 MMscf/d are not acceptable and more study is needed to estimate exponential constant values for these rates.

From the values of exponential constants for gas flow rate of 1 and 5 MMscf/d which are acceptable due to low errors (Table 7-1), one can see that the ratio of gas flow rate ($\frac{q_2}{q_1}$) varies almost directly to the product of the ratios of area, thickness, and porosity. In other words, $\frac{q_2}{q_1}$ varies almost directly to the ratio of pore volume ($\frac{V_2}{V_1}$). The exponent d for the permeability ratio ($\frac{k_2}{k_1}$) is very close to zero for both the 1- and 5- MMscf/d cases. This means that permeability has almost no effect on the $\frac{q_2}{q_1}$ ratio.

The above finding is not the same as that adopted in the petroleum industry. It has long been believed that the allocation of rate for a multi-layered reservoir can be obtained by using the kh allocation concept which is based on the application of Darcy's equation to a parallel cylindrical system. The finding obtained by this study is totally different from the kh allocation concept. Therefore, it should be investigated why the finding in this study is different from the kh allocation concept and how good this finding is.

As mentioned before, in Figure 7-1, at the beginning of production period the rate allocation obeys the kh allocation concept, but after this starting point, the rate allocation does not obey the kh allocation concept and deviates to the trend that obeys the pore-volume allocation concept as shown in Table 7-1. Here, it can be interpreted as follows. At the beginning, the flow into a well behaves as predicted by the Darcy's equation. Later, when reservoir pressure drops and flow in the well is influenced by expansion of gas in the reservoir (volumetric reservoir), the flow (including flow rate) is controlled by increasing volume of gas in the reservoir and finally by all gas in the reservoir, hence pore volume, when pressure drop is felt at the boundary of the reservoir.

During the transition period, from the beginning of the time that flow is influenced by all gas in the reservoir, both permeability and gas in depleted zone (in the reservoir) influence flow in the reservoir into the well. It is expected that when flow is controlled by al gas in the reservoir, permeability still has some influences on the flow, but to a much less extent for the case in Figure 7-1 where flow rate is low. However, for high flow rate cases, it is expected that the permeability will have more influence, relative to the cases of low flow rate, on flow into the well, while the pore volume (or the gas volume, to be exact) will have less influence, relative to the cases of low flow rate, on flow. This can roughly be verified by increase in values of exponent d and decrease in values of exponents a, b, and c when flow rate increases (Table 7-1). For high gas flow rate, this conclusion is approximation in nature because the exponential constants (a, b, c, and d) give poor correlation at high flow rate.

From the above discussion, the following can be concluded for allocation of rate for a two-layered reservoir:

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 on flow rate allocation seems to decrease and the influence of permeability seems to increase.
3. at low rate, the influence of permeability on flow rate ;allocation can be considered as negligible and the rate allocation can be considered to be solely influenced by pore volume of each layer.

These conclusions are very useful in allocation of flow rate for each layer when the separated method is used to estimate GIIP.

7.2 Separated-layer method

In separated-layer method, rock and fluid properties and conditions for each layer must be known. The bottom-hole flowing pressure (p_{wf}) must also be known. Then, the ratio $\frac{q_2}{q_1}$ can be calculated using Equation 7-1 and exponential constants given in Table 7-1. However, it is recommended that exponential constants in Table 7-1 be used for the cases of 1 and 5 MMscf/d only. After that, knowing total flow rate (q_T), q_1 and q_2 can be calculated. Then, $\bar{p}$ for each layer can be obtained using these q_1 and q_2 and the pseudo-steady state equation. Having $\bar{p}$ for each layer, p/z plot for each layer can be prepared, and then the estimated GIIP for each layer can be obtained. The total GIIP of the whole reservoir system is the sum of GIIP of each layer.

Several cases of a two-layered reservoir system were selected for study of the application of the separated method. The properties of the typical parameters and the allocated rates are shown in Appendix B.

The calculated results for these cases are shown in Table 7-2. The results in Table 7-2 imply that use of the separated method to estimate GIIP for a two-layered reservoir system is acceptable. The errors are quite low, less than 10%.

It should be noted that for the case of a two-layered reservoir, not only the deficiency of the pseudo-steady state equation that causes errors in estimated GIIP's (as in the case of a single-layered reservoir), but also the inaccuracy in estimation of q_1 and q_2 and the approximation that each layer flow at constant for all time under study.

Deficiency of the pseudo-steady state equation, inaccurate estimation of q_1 and q_2, and constant rate approximation, in fact, cause errors in estimated $\bar{p}$ which, in turn, causes errors estimated GIIP.

In addition, for both single-layered and two-layered reservoir, the selected regression (straight) line to fit data points on the p/z plot also cause errors in estimate GIIP.

It is possible errors in drawing a regression line may have more influence in causing errors in GIIP than errors in inaccurate estimation of $\bar{p}$. This is shown in Figure 7-2 and 7-3. Here, errors in calculation of $\bar{p}$ of layer 1 (Figure 7-2) are higher than that of layer 2 (Figure 7-3), but the error in GIIP for layer 1 is lower than that of

Table 7-2 GIIP obtained from application of the separated-layer method to four different cases.

Case	k (md)		ϕ (fraction)		h (ft)		Layer	GIIP (MMscf)			Error of GIIP from a P/Z plot (%)	
	Layer1	Layer2	Layer1	Layer2	Layer1	Layer2		Volumetric	Simulation	PSSE	Using Pavg from Sim.	Using Pavg from PSSE
1	100	50	0.1	0.2	30	30	1	3,337	3,432	3,260	+2.9	-2.3
							2	6,761	6,835	7,118	+1.1	+5.3
							Total	10,098	10,267	10,378	+1.7	+2.8
2	100	50	0.2	0.2	30	30	1	6,674	6,817	6,825	+2.1	+2.3
							2	6,761	6,855	7,224	+1.4	+6.8
							Total	13,435	13,672	14,049	+1.8	+4.6
3	20	100	0.3	0.1	30	30	1	10,011	10,211	8,858	+2.0	-11.5
							2	3,381	3,432	3,571	+1.5	+5.6
							Total	13,392	13,643	12,429	+1.9	-7.2
4	100	20	0.3	0.1	30	15	1	10,011	10,221	8,938	+2.1	-10.7
							2	1,690	1,719	3,501	+1.7	+107.2
							Total	11,701	11,940	12,439	+2.0	+6.3

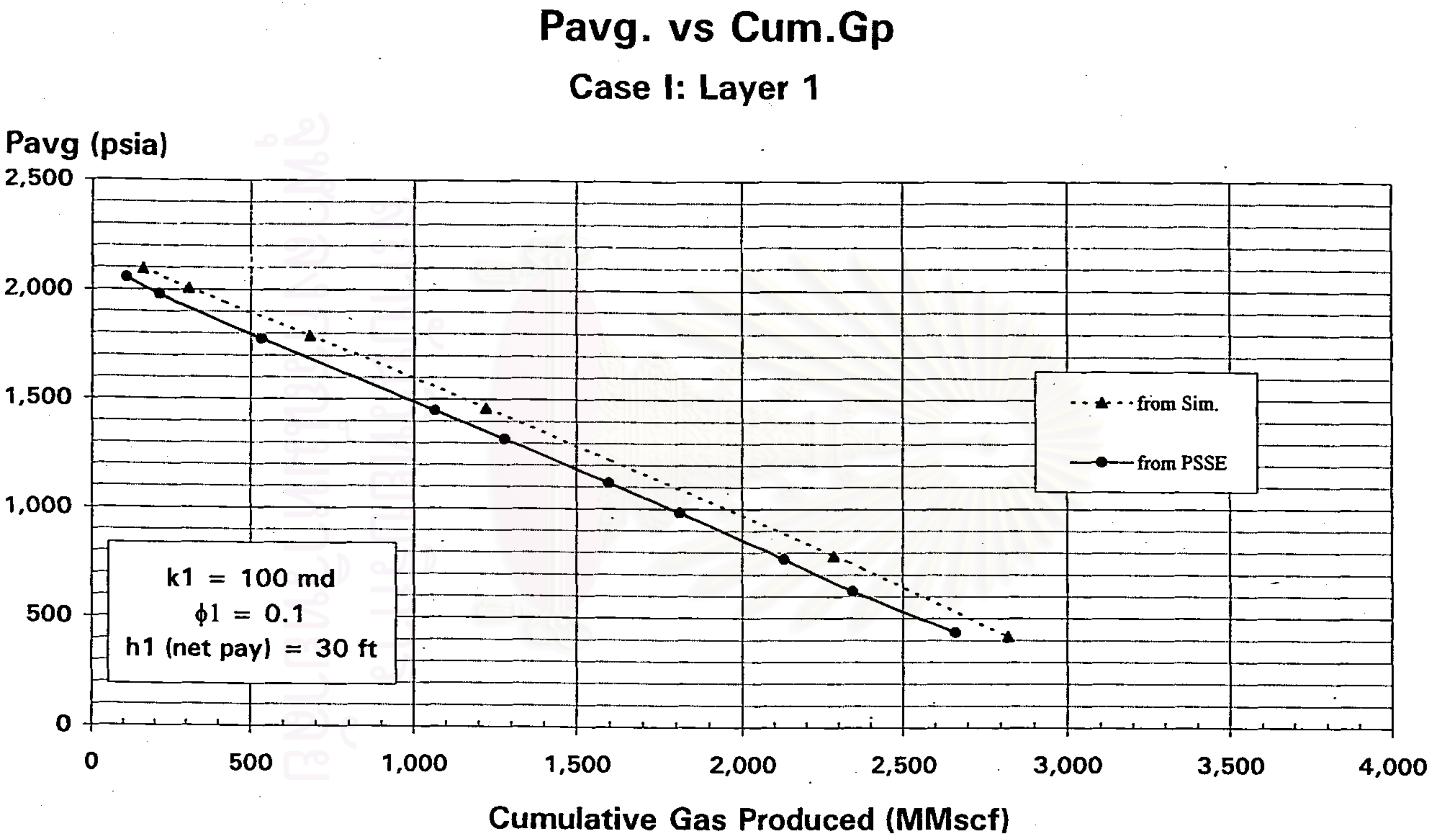

Figure 7-2 Relationship between cumulative gas production and average reservoir pressure for layer 1 of case I

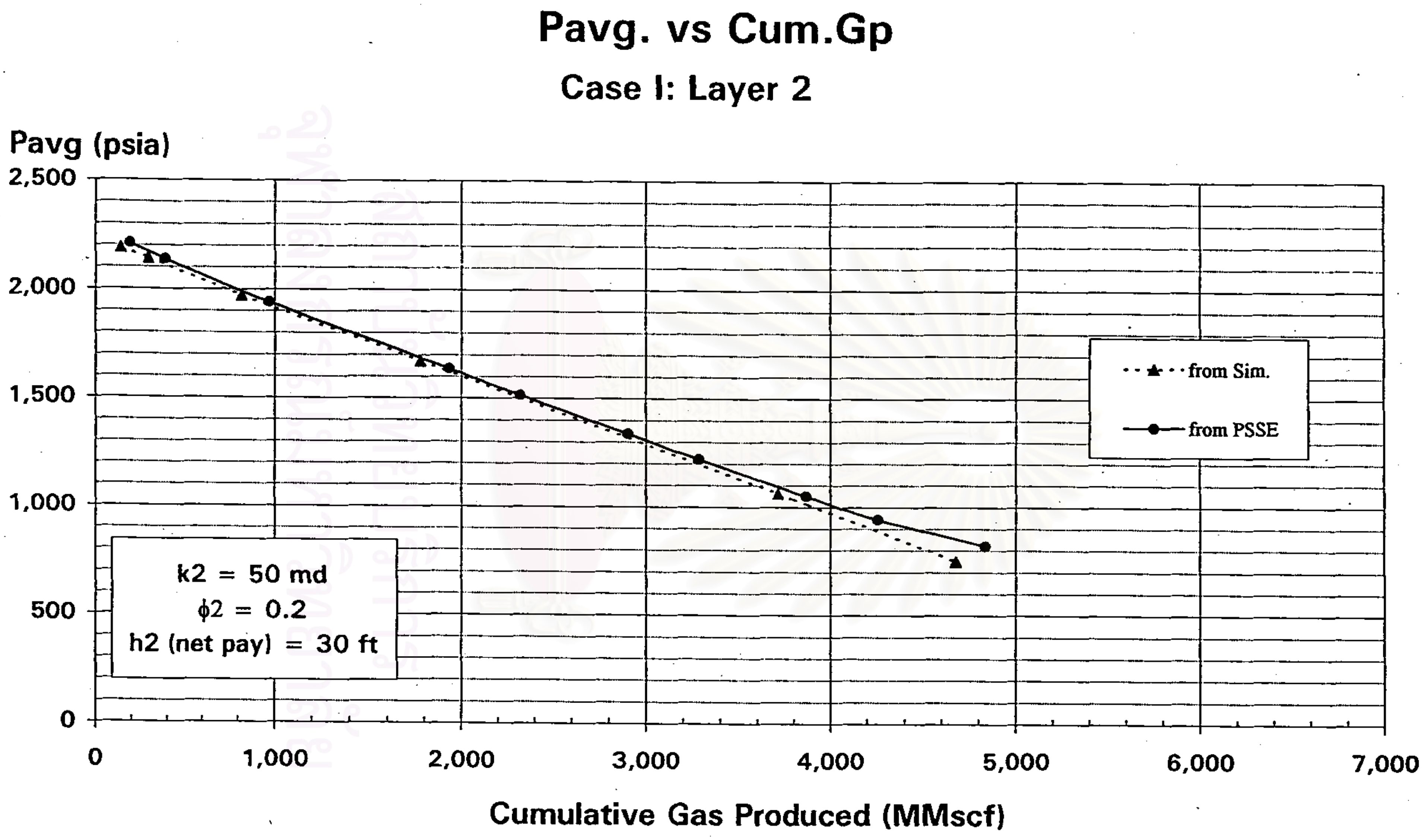

Figure 7-3 Relationship between cumulative gas production and average reservoir pressure for layer 2 of case I

layer 2. This implies that error due to drawing a regression line may have more influence than errors due to estimation of $\bar{p}$.

7.3 Combined-layer method

In the combined-layer method, reservoir parameters are averaged and shown in Table 7-3.

After average properties (ϕ and k) and the total thickness of two layers were obtained, all these obtained parameters will be used together with known total flow rate (q_T) in the pseudo-steady state equation to calculate $\bar{p}$ of the system (the two layers). (Drainage area of each layer, in the study of the combined method, was assigned to be the same for all the layers).

The results of the combined method are shown in Table 7-4. The errors in estimated GIIP are also low for the combined method. All errors in the cases studied are lower than 5%. This means that the combined method should be acceptable for estimation of GIIP.

Comparison of errors in estimated GIIP by the separated and combined methods are shown in Table 7-5. The combined method seems to give better results for the cases used in this study. However, it can be concluded that both methods should be acceptable for calculation of GIIP.

Table 7-3 Average parameters of the four cases used in the combination method.

Case	k (md)			ϕ (fraction)			h (ft)		
	Layer1	Layer2	average*	Layer1	Layer2	average*	Layer1	Layer2	Total
1	100	50	67	0.1	0.2	0.15	30	30	60
2	100	50	75	0.2	0.2	0.2	30	30	60
3	20	100	40	0.3	0.1	0.2	30	30	60
4	100	20	89	0.3	0.1	0.23	30	15	45

average* = volume average

Table 7-4 GIIP obtained from application of the combination method to the four different cases.

Case	k (md)		ϕ (fraction)		h (ft)		GIIP (MMscf)			Error of GIIP from a P/Z plot (%)	
	Layer1	Layer2	Layer1	Layer2	Layer1	Layer2	Vol.	Sim.	PSSE	Pavg from Sim.	Pavg from PSSE
1	100	50	0.1	0.2	30	30	10,098	10,270	10,350	+1.7	+2.5
2	100	50	0.2	0.2	30	30	13,454	13,663	14,040	+1.7	+4.5
3	20	100	0.3	0.1	30	30	13,392	13,663	12,789	+1.8	-4.5
4	100	20	0.3	0.1	30	15	11,701	11,923	12,064	+1.9	+3.1

Table 7-5 Comparison of the errors of GIIP obtained from the separated and combination methods.

Case	Error of GIIP from a P/Z plot (%)			
	Separated Method		Combined Method	
	Using Pavg from Sim.	Using Pavg from PSSE	Using Pavg from Sim.	Using Pavg from PSSE
1	+1.7	+2.8	+1.7	+2.5
2	+1.8	+4.6	+1.7	+4.5
3	+1.9	-7.2	+1.8	-4.5
4	+2.04	+6.3	+1.9	+3.1

7.4 Two-layered reservoir with two wells

Two-layered reservoir with two wells can be separated into two main cases: 1. the case that each well penetrates both of the two layers (Figure 5-4), 2. the case that one of the two wells penetrates only one layer (upper layer), while the other penetrates both of the two layers (Figure 5-5)

7.4.1 The case that each well penetrates both of the two layers

For this case, in the study, both of the separated and combined methods were applied for both wells and layers. In other words, it can be said that, for this case, separated-layer and separated-well, separated-layer and combined-well, combined-layer and separated-well, and combined-layer and combined-well methods were used.

The case of a two-layered reservoir with two wells where each layer has the same reservoir characteristics and properties, and each of the two wells is located symmetrically to each other and produces at the same constant rate (of 7.5 MMscf/d) was used in the study of the validity of the four different methods. The reservoir characteristics and properties of each of the two layers in the studied case are as follows: permeability = 20 md, porosity = 0.2, and thickness = 30 ft.

The separated-layer and separated-well method

This method can be used when the flow rate can be allocated to each layer, and the rate of the two wells are constant. If the flow rate can be allocated to each layer, by knowing p_{wf} at the depth of each layer, $\bar{p}$ of each layer can be calculated from the pseudo-steady state equation.

For a two-layered reservoir with two wells where each of the two wells penetrates both of the two layers, the flow rate allocated to each layer can be easily estimated when the two layers have the same reservoir characteristics and properties (A, h, ϕ, and k). For this case, the allocated flow rate of each layer will be equal. However, if the two layers have different reservoir characteristics and properties, the allocation of each layer is still possible to estimated if all those reservoir characteristics and properties (A, h, ϕ, and k) of each layer are known and the flow rates of the two wells are constant.

For such a case (two layers having different reservoir characteristics and properties), when the flow rates of the two wells are constant, fictitious boundary of drainage area of each well on the two layers does not change with time. Therefore, drainage volume of each well should also not change with time (constant or almost constant). For this case, it is assumed that there is no flow across the fictitious boundary of the two wells. Each well (drainage volume of each well), then, can be considered separately. In other words, it can be said that for such a case, the separated-well method can be applied.

In the studied case, because of the symmetry of the well locations and the constant production rate of each well and the similarity of the reservoir characteristics and properties of each layer, the separated-layer and separated-well method could be applied. The separated-layer and separated-well method would divide the whole volume of the system into four separated volumes. Those are the volumes of : layer 1-well A, layer 1-well B, layer 2-well A, and layer 2-well B. Initially, the whole volume was divided into the volumes of well A and well B, then using the two obtained fictitious two-layers-and-one-well systems (for well A and well B) with the flow rate allocation equation (Equation 7-1) to allocate the flow rate of each well to each layer (to divide the total drainage volume of well A (or well B) to be the volumes of layer1-well A (or well B), and layer 2- well A (or well B)).

After all the four separated volumes were obtained, the same procedure as what previously done to yield a p/z plot for each of the separated volume was again carried out. For each volume (either layer 1 - well A, layer 1 - well B, layer 2 - well A, or layer 2 - well B), $\overline{p}$ was obtained from the PSSE using the allocated flow rate of that volume and p_{wf} of that well and that layer (obtained from the simulator). The p/z plot of each volume would yield the GIIP of that volume. The sum of the GIIP of each volume is the total GIIP of the system (of the two layers).

The results from the application of the separated-layer and separated-well method to the studied case are shown in Table 7-6.

Table 7-6 Comparison of the four different methods for a two-layered reservoir with two wells.

Method	GIIP (MMscf)												Error of GIIP from a P/Z plot (%)								
	Actual			From a P/Z plot using Pavg from PSSE																	
	Well A+ Well B			Well A			Well B			Well A+ Well B			Well A			Well B			Well A+ Well B		
	Layer1	Layer2	Total	Layer1	Layer2	Total	Layer1	Layer2	Total	Layer1	Layer2	Total	Layer1	Layer2	Total	Layer1	Layer2	Total	Layer1	Layer2	Total
Separated Layer and Separated Well	6,674	6,761	13,435	3,545	3,527	7,072	3,545	3,527	7,072	-	-	-	+6.2	+4.3	+5.3	+6.2	+4.3	+5.3	-	-	-
Separated Layer and Combined Well	6,674	6,761	13,435	-	-	-	-	-	-	7,188	7,133	14,321	-	-	-	-	-	-	+7.7	+5.5	+6.6
Combined Layer and Separated Well	6,674	6,761	13,435	-	-	7,080	-	-	7,080	-	-	-	-	-	+5.4	-	-	+5.4	-	-	-
Combined Layer and Combined Well	6,674	6,761	13,435	-	-	-	-	-	-	-	-	14,148	-	-	-	-	-	-	-	-	+5.3

The separated-layer and combined-well method

This method will transform a two-layered reservoir with two wells to be a two-layered reservoir with one fictitious well located at the middle of the system. Like what was done in the study of a two-layered reservoir with one well, rate allocated to each layer can be determined from Equation 7-1. From the obtained allocated rate and p_{wf} of each layer from the simulation, $\bar{p}$ of each layer can be obtained from the pseudo-steady state equation. Again, from the p/z plot of each layer, the GIIP of each layer can be estimated.

The results of the studied case using the separated-layer and combined-well method are shown in Table 7-6.

The combined-layer and separated-well method

This method will transform a two-layered reservoir with two wells to be a fictitious single-layered reservoir with two wells. The obtained fictitious single-layered reservoir will have the properties as the average ones (volume averaging) except the thickness which is equal to the sum of the thickness of each layer. In the studied case, because of the symmetry of the well locations and the constant production rate of the two wells, the separated-well method could be applied. Therefore, from the obtained fictitious single-layered reservoir with two wells, the drainage volume of each well can be separately considered. For each drainage volume, $\bar{p}$ can be determined from the pseudo-steady state equation, then, a p/z plot can be prepared. The sum of the GIIP of the drainage volume of each well is equal to the total GIIP of the system.

The results from the application of the combined-layer and separated-well method to the studied case are shown in Table 7-6.

The combined-layer and combined-well method

This method will transform a two-layered reservoir with two wells to be a fictitious single-layered reservoir with one fictitious well located at the middle of the system. From the application of this method, the obtained fictitious layer will have the properties as the average ones, as previously mentioned. While, the obtained fictitious well will have the flow rate equal to the total flow rate of the two wells in the system (the actual system prior to the system transformation). For the application of this method, only one p/z plot representing the whole system will be generated. Therefore, the GIIP obtained from that p/z plot will be the GIIP of the system. The results of the studied case using this method are also shown in Table 7-6.

From Table 7-6, the errors of the resulting GIIP from applications of the four different methods are within the same range (5.3% - 6.6%). Therefore, it can be said that for the reservoir system similar to the system in the studied case (two-layers-and-two-wells system where each layer has the same reservoir characteristics an properties, and each well in the system is located symmetrically to each other and produces at the same constant rate), all the four different methods can be used with the same range of errors expected from the four different methods. It can be noticed that the errors of the resulting GIIP's will be decreased if the permeability of the layers is higher (higher than 20 md which is the permeability of the layers in the studied case).

7.4.2 The case that one of the two wells penetrates only one layer

For this case, the study was initially tried with all the four methods (separated-layer and separated-well, separated-layer and combined-well, combined-layer and separated-well, and combined-layer and combined-well). However, it was found that the separated-layer and separated-well, separated-layer and combined-well, combined-layer and separated-well methods could not be applied to this system because flow rate allocated to each layer could not be achieved. Therefore, only the combined-layer and combined-well method was applied. The system selected for this study is similar to the system in the study of a two-layered reservoir with two wells where each well in the system penetrates both layers. The difference is that, for this study, one of those two wells penetrates only one layer (upper layer). However, for this study, the two wells were still assigned to produce at the same constant rate of 7.5 MMscf/d.

The GIIP of the system (layer 1+ layer 2) from a p/z plot using $\bar{p}$ from the pseudo-steady state equation, the practical GIIP, is 14,416 MMscf or +7.3% error from the actual value of 13,435 MMscf. From the result of the study, it could be said that for the two-layered system with two wells, in which one of the two wells penetrates only one layer, the combined-layer and combined-well method (which is the only method suitable for this system) can be applied with an acceptable error of the resulting GIIP (of the system).

7.5 Three-layered reservoir

For this study, both of the separated-layer and combined-layer methods were used. For the case selected, all the three layers were assigned with the same reservoir conditions and properties: k = 20 md, $\phi = 0.2$, and h = 30 ft. The results from the study are shown in Table 7-7. The results show that with the application of the separated-layer method, the error of the obtained GIIP (practical GIIP) of each layer is within the same range (6.3% - 10.4%). The error of the practical GIIP of the topmost layer is the largest (10.4%), while that of the bottommost layer is the smallest (6.3%). With the application of the separated-layer method, the error of the total GIIP of all layers is 8.3%, which is equal to the error of the obtained GIIP of the whole system when the combined-layer method is applied.

Therefore, for a three-layered reservoir with one well where all layers have the same reservoir characteristics and properties, both separated-layer and combined-layer methods can be applied with the same error of the calculated GIIP (of the whole system) expected to be obtained. Another interesting point to notice is that all the errors (from applications of both methods) will be smaller if all the layers in the system have higher value of permeability (as mentioned in the study of the effect of permeability on the calculated GIIP).

For a three-layered reservoir with one well, if all layers have different reservoir characteristics and properties, the separated-layer method is not recommended due to difficulty in determining correct flow rate allocated to each layer. For such a case, to determine the allocated flow rate of each layer, correlation between all reservoir

Table 7-7 Comparison of the GIIP obtained from the two different method for a three-layered reservoir with one well

Layer	GIIP (MMscf)			Error of GIIP from a P/Z plot (%)	
	Actual	From a P/Z plot using Pavg from PSSE		Separated Layer Method	Combined Layer Method
		Separated Layer	Combined Layer		
1	6,674	7,370	-	+10.4	-
2	6,761	7,322	-	+8.3	-
3	6,846	7,275	-	+6.3	-
Total	20,281	21,967	21,972	+8.3	+8.3

parameters and gas flow rate of each layer are needed to be studied and developed like what was done in the study of a two-layered reservoir with one well. (It is expected that the obtained equation or correlation for such a system will not be as same as that shown in Equation 7-1. Therefore, to avoid difficultiy in allocating flow rate to each layer, the combined-layer method is suggested. Even if there is no further investigation for such a case, it is expected, from the results in Table 7-7, that the combined-layer method should be able to be applied with an acceptable error of the calculated GIIP.

Further study for a more complex system than those used in this study (more complex than a two-layered reservoir with one well, a two-layered reservoir with two wells, and a three-layered reservoir with one well) can be carried out with the application of the four different methods (separated-layer and separated-well, separated-layer and combined-well, combined-layer and separated-well, and combined-layer and combined-well). Criteria used in this study: constant gas flow rate of each well (used to select either separated-well or combined well method), and similarlity of reservoir characteristics and properties of each layer (used to select either separated-layer or combined-layer method) can also be used in the study of a more complex system.

The technique used to generate a flow-rate-allocation equation for a two-layered reservoir with one well (Equation 7-1) can be followed and modified for a more complex system. It is noted that if a good flow-rate-allocation equation can be generated for any system, a separated-layer method then could also be used for that system.