Gala Reservoir Engineering Study

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ABSTRACT

In this thesis, I do reservoir engineering study of a reservoir in South Sumatra, Ra Reservoir, to develop better understanding of Ra Reservoir in order to develop better Ra Reservoir Model. It will discuss the reservoir fluid study, the reservoir continuity study, and the reservoir drive mechanisms using material balance to develop better Gala Reservoir Model.

And based on the study, Gala is a slightly retrograde gas reservoir which can be treated as a wet gas reservoir, and the best model for Gala Reservoir is one tank with leaking-fault-and-water-influx. And “leaking fault” is a new additional consideration in Gala Reservoir Model.

Finally, in my limited thesis, I hope this thesis can give benefit for anyone who read and want to know about reservoir study in Gala Reservoir which I have done on September 2007 to December 2007.

Keywords: reservoir fluid, geological study, p/z, leaking fault, tank, advanced material balance
INTRODUCTION

The Gala reservoir is a sandstone gas reservoir located in South Sumatra. Based on composition from five producer wells, i.e. GL-1, GL-2, GL-3, GL-5, GL-6, Gala Reservoir indicates to have a “common single” reservoir fluid type.

In Gala Reservoir there is a big fault which divides Gala Reservoir to be two parts, to be West Gala and South East Gala. West Gala is bigger than South East Gala. The fault is not known seal/leak because there are no fault seal analysis and no interference test between West Gala and South East Gala.

The field has six wells, five producers and one water disposal well. In West Gala, there are four producer wells (GL-1, GL-3, GL-5, and GL-6) and one water disposal well (GL-4). Then in South East Gala, there is only a producer well (GL-2).

In Gala Reservoir, the early pressure data collected in the field suggested GL-2, where is located in South East Gala, was separated from the rest of the field. When perforations were added in GL-6, the pressure in GL-2 began to move toward the pressure of the other wells in the field, it is shown in Figure 1. So, West Gala and South East Gala is likely to have connection, and the fault which divides Gala Reservoir to be two parts is likely as a non-sealing fault. And there are no interference test and fault seal analysis between West Gala and South East Gala to confirm the big fault seal or leak.

GL-2 produces with a high water cut while the rest of the field only produces condensed water. Then the field’s Condensate-Gas Ratio has declined over time.

RESERVOIR FLUID STUDY

Based on fluid sampling in GL-1, GL-2, GL-3, GL-5, and GL-6 in 2001, the compositions of carbon dioxide (CO₂), Nitrogen (N₂), methane are almost the same, it can be seen on Table 1 CO₂ (15%), N₂ (0.23%), methane (74%), so Gala Reservoir has a “common single” reservoir fluid type.

Because Original Gas in Place is confidential data, volumes presented are normalized. A volume of 1.0 represents the OGIP estimated from the straight line P/z analysis.

![Figure 1 p/z plot of Gala](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>GL-1</th>
<th>GL-2</th>
<th>GL-3</th>
<th>GL-05</th>
<th>GL-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>15%</td>
<td>14.96%</td>
<td>15.95%</td>
<td>15.73%</td>
<td>14.83%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.23%</td>
<td>0.23%</td>
<td>0.21%</td>
<td>0.21%</td>
<td>0.24%</td>
</tr>
<tr>
<td>Methane</td>
<td>74.73%</td>
<td>74.34%</td>
<td>72.79%</td>
<td>73.89%</td>
<td>74.46%</td>
</tr>
</tbody>
</table>

Reservoir fluid model is derived from Gala-1 in 1991. The Gala-1 recombined sample is chosen because it is first sample in Gala Reservoir. And moreover based on the fluid sampling, there is liquid drop in depletion test, so the best representative sample
is fluid sample of Gala-1 in 1991 because it has the smallest possibility liquid drop in the reservoir.

In this study, water (condensed water) during the sampling can be ignored, because reservoir pressure was still high and water vapor is excluded in calculation.

**Constant Volume Depletion Calculation**

Based on Constant Volume Depletion (CVD) calculation using tuned EOS, Figure 2, maximum liquid drop is very small, 0.2 % in between 1114.7 psia and 614.7 psia, so liquid drop can be ignored. Then Gala as a slightly retrograde gas reservoir can be treated as a wet gas reservoir.

**Flash Calculation**

In flash calculation, reservoir fluid composition is assumed constant between initial condition and abandonment condition.

Figure 3 describes equilibrium in the reservoir between initial pressure and abandonment pressure at constant reservoir temperature (isothermal process). And Table 2 is the table which describes flash result for Gala Reservoir between initial pressure and abandonment pressure at constant reservoir temperature.

Based on the flash result, % mole liquid maximum is very small, i.e. 0.19 %, so % mole liquid can be ignored. Therefore, reservoir fluid is treated always 100% mole vapor or a slightly retrograde gas reservoir is treated as a wet gas reservoir.

This reservoir fluid study can explain the field’s Condensate-Gas Ratio which decline over time, because Gala Reservoir is a slightly retrograde reservoir in reality.

**RESERVOIR CONTINUITY STUDY**

Gala Geology Model is an anticline and this reservoir is divided to be two parts as West Gala and South East Gala separated by the big fault.
In Gala Reservoir, there is no fault seal analysis. So, fault seal analysis is assumed based on only clay smear potential. As analogy in the left most Gala fault, throws are between 25 and 40 meters, and the fault has been seal in the left most side. It is illustrated in Figure 4 in black circle area.

Based on analogy with the left most Gala fault, the following assumption is made, if the throw is more than 25 meters, the fault seals, and if the throw is less than 25 meters, the fault might seal or leak. So, Gala Reservoir Model may have three possible reservoir models, i.e. 2 tanks, 1 tank, and 1 tank with leaking fault.

First, Gala Reservoir Model is two tanks, if the fault is a sealing fault. Second, Gala Reservoir Model is one tank, if the fault is a non-sealing fault and gas can flow without restriction from one compartment toward the other compartment. Gala Reservoir Model is one tank with leaking fault, if the fault is a non-sealing fault and this fault makes poor connection between two compartments. The area where the fault might leak or seal is predicted based on throw less than 25 meters as it is shown in Table 3.

<table>
<thead>
<tr>
<th>upper side</th>
<th>lower side</th>
<th>throw</th>
</tr>
</thead>
<tbody>
<tr>
<td>1690</td>
<td>1716</td>
<td>26</td>
</tr>
<tr>
<td>1680</td>
<td>1712</td>
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<td>1680</td>
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</tr>
<tr>
<td>1764</td>
<td>1800</td>
<td>36</td>
</tr>
<tr>
<td>1759</td>
<td>1790</td>
<td>31</td>
</tr>
</tbody>
</table>

The area where the fault might leak or seal is illustrated in Figure 4 in orange circle area.

TANK MODEL ANALYSIS

Tank model calculation procedure is shown in Appendix A. And its calculation assumes Gala reservoir fluid as a wet gas reservoir and water allocation is correct.

Based on Repeat Formation Test (RFT) of GL-1, GL-2, GL-3, GL-4, and GL-6, it shows that the zone has one pressure system, so Gala Reservoir can be treated as a tank model. It is illustrated in Figure 5.

RFT of GL-6 is assumed to have one pressure system too, because from Production Logging Tools (PLT) of GL-6, gas produced 98.2% from zone 3. And it is assumed that GL-6 has “one pressure system” because production almost from zone 3 only (98.2%≈100%).
Gala Reservoir as 2 Tanks

South East Gala Reservoir

P/z plot of GL-2 (South East Gala) has concave up and then concave down (Figure 6).

1. Pressure gradient of GL-2 is less than 0.5 psi/ft, so Gala reservoir is not an overpressure reservoir.
2. Condensation in reservoir can be ignored as CVD result, so it can be treated as a wet gas reservoir.
3. Figure 7 show high salinity in GL-2 which indicates formation water encroachment in GL-2. So we can make 2 tanks which South East Gala has concave p/z because of water influx. Then South East Gala can be treated as single tank, and Gala to be 2 tanks.
4. Based on geological data, it might have leaking fault, so the Gala reservoir may one tank with leaking fault and water influx.

West Gala Reservoir

Based on p/z of West Gala as single tank model is acceptable at the early time, but lately the points move away slightly from the line. It is illustrated in Figure 8. So, West Gala can be assumed as single tank.

Generally, concave in p/z plot can be caused by an overpressure reservoir, condensation in the reservoir, leaking fault (poor connection reservoir), and water influx.

Here are the individual explanations

Figure 5 RFT of Gala Wells

Figure 6 p/z plot of Gala 2 as single tank

Figure 7 High Salinity in GL-2
Gala Reservoir as 1 Tank

As it is shown in Figure 9, there is significant variation pressure in early production, so Gala Reservoir cannot be treated as 1 tank.

Finally, based on geological data, Gala Reservoir might be 1 tank, 2 tanks, or 1 tank with leaking fault, but based on tank model analysis Gala is not 1 tank. So, based on geological data and tank model analysis, Gala Reservoir is 2 tanks or 1 tank with-leaking-fault-and-water-influx.

“EVENT IN 2001”

Event in 2001 is an additional note and it strengthens the opinion that there is a leaking fault in Gala Reservoir. In this study, leaking fault is a new additional consideration for Gala Reservoir Model. And it is the best and it is the one we will use going forward.

South East Gala Reservoir (the red box) and West Gala Reservoir (the blue box) have same initial pressure as illustrated on Figure 10(a). Before February 2001, South East Gala had faster pressure drop than West Gala, so South East Gala pressure is lower than West Gala pressure, because there is a leaking fault, so gas flows from West Gala to South East Gala. This condition is illustrated on Figure 10(b).

In February 2001, GL-6, which is in West Gala, started producing. Because contract gas rate before 2001 and after 2001 same, other wells rate must be reduced. The other hand, GL-2 produced water with high water cut, while the rest of the field only produced condensed water. So, in February 2001 gas rate of GL-2, which the only one producer well in South East Gala, is significantly decreased, 3.5 times. As we know when production or gas rate is smaller, pressure drop in reservoir is smaller too. So, pressure drop in South East Gala get slower than pressure drop before.

If the relationship between rate and pressure drop is assumed linear, because gas rate decreased 3.5 times, then pressure drop of GL-2 decreased 3.5 times than before. Actually, decreasing pressure drop is smaller, because Gala Reservoir is a gas reservoir, so rate should be proportional with \((P_1^2-P_2^2)\) and not be proportional with \((P_1-P_2)\). On the other hand, gas rate of West Gala get slightly bigger than before, because total gas rate increase 1.1 times in February 2001. It is caused by starting gas produced in GL-6. If we assume the relationship between rate and pressure drop is linear like previous statement, pressure drop of West Gala increase 1.1 times than pressure drop before.

In 2001, gas rate of South East Gala decrease 3.5 times, and pressure drop was getting
slower 3.5 times. On the other hand, pressure drop of West Gala in 2001 gets faster 1.1 times, so pressure between South East Gala and West Gala might be closer after 2001. It is illustrated on Figure 10(c).

Figure 10 “Event in 2001”
(a) Both West Gala and South East Gala have same initial pressure
(b) Pressure of South East Gala was lower than Pressure West Gala
(c) Pressure of South East Gala is getting closer to Pressure of West Gala

And “Event in 2001” is summarized in Figure 11.

Figure 11 Summary of “Event in 2001”

MATERIAL BALANCE OF GALA RESERVOIR

As the previous explanation, because of salinity of Gala wells, geological analysis, and tank model analysis, Gala remaining models are 2 tanks and 1 tank with-leaking-fault-and-water-influx.

Gala Reservoir As 2 Tanks

West Gala Reservoir is calculated as a volumetric reservoir because p/z plot of West Gala almost straight line. And based on MBAL result, drive mechanisms of West Gala reservoir are fluid expansion, and pore volume (PV) compressibility. If there is water encroachment, it is very small and ignorable. It is illustrated in Figure 12.

Figure 12 Drive Mechanisms of West Gala when Gala Reservoir as 2 tanks
Based on the best fit result with analytical method, original gas in place (OGIP) of West Gala Reservoir is 0.85. The result is shown in Figure 13.

South East Gala Reservoir is calculated as a wet gas reservoir with water influx because high salinity indicates water influx. And drive mechanisms of South East Gala reservoir from MBAL drive mechanism result are fluid expansion, PV compressibility, and water influx as Figure 14.

From the best fit using analytical method, OGIP of South East Gala Reservoir is 0.065. The result is shown in Figure 15. But it has poor match when concave down, as it is known that water drive will be hard to have significant concave down.

Total OGIP of Gala Reservoir is 0.85+0.065 = 0.915.

West Gala Reservoir is calculated as a volumetric reservoir. Based on MBAL drive mechanism result, drive mechanisms of West Gala Reservoir are fluid expansion, and PV compressibility.

Based on the best fit with graphical method, OGIP of West Gala reservoir is 0.88. The result is in Figure 16.
South East Gala Reservoir is calculated as a wet gas reservoir with water influx. And drive mechanisms of South East Gala reservoir are fluid expansion, PV compressibility, and water influx based on drive mechanism MBAL result. Because Gala Reservoir has transmissibility which can cause concave p/z, and there is water influx in South East Gala which can cause concave p/z too, so there is two variable which can cause concave p/z. Unfortunately, aquifer can not be known exactly. And transmissibility can not be determined because there is no interference test in Gala Reservoir. Because there are two variables which can cause concave p/z, we have multiple matches for original gas in place (OGIP) South East Gala Reservoir (Figure 17) and drive mechanisms of South East Gala Reservoir (Figure 18) for each scenario.

![Figure 17 Examples of Multiple Matches in South East Gala](image)

(a) Case which OGIP of South East Gala is 0.06
(b) Case which OGIP of South East Gala is 0.065
(c) Case which OGIP of South East Gala is 0.07

Minimum limit of OGIP of South East Gala is derived from South East Gala gas produced, 0.06 (Figure 17(a)). Then to get maximum limit of OGIP of South East Gala, produced water was added into produced gas as water equivalent, and the wet gas reservoir with water influx was approached with a volumetric reservoir. The reservoir is assumed to have bounded aquifer, and it is produced into 0 psig. Then fluid produced will be same between 1-tank-with-leaking-fault-and-water-influx and 1 tank with leaking fault only, it is illustrated in Figure 19.

![Figure 18 Drive Mechanisms of Gala when South East Gala has multiple matches](image)

(a) Case which OGIP of South East Gala is 0.060
(b) Case which OGIP of South East Gala is 0.065
(c) Case which OGIP of South East Gala is 0.070
From this assumption, maximum limit of OGIP of South East Gala is 0.078, the result can be seen in Figure 20.

The OGIP from above calculation is assist to predict initial maximum limit of OGIP of South East Gala. The blue line represents line of a wet gas reservoir with water-influx-and-transmissibility, and the red line represents line of a wet gas reservoir with only transmissibility. The blue line will be same with the red line, if OGIP of Tank 2 is 0.076. This explanation is shown on Figure 21. It is wrong, because the blue line is same with the red line when Tank 2 has ignored water influx but actually Tank 2 has high water cut.

Then if OGIP of South East Gala is assumed 0.07, the blue line and the red line are slightly different, so 0.07 is taken as maximum limit of OGIP of South East Gala. It is illustrated on Figure 22.

Based on 1 tank with leaking-fault-and-water-influx model, prediction OGIP of Gala reservoir is between 0.88+0.06=0.94 and 0.88+0.07 = 0.95. If the maximum OGIP of South East Gala is taken as OGIP of South East Gala, 0.07, then recovery factor has 0.84. It is likely very high recovery factor for reservoir with water influx, but leaking fault consideration cause 84% recovery factor in reservoir with water influx (South East Gala) may occur. Because leaking fault may transfer gas from

Figure 19 The wet gas reservoir with water influx is approached with a volumetric reservoir

Figure 20 Approach of Volumetric Calculation of South East Gala to get maximum limit of OGIP of South East Gala

Figure 21 Case which OGIP of South East Gala is 0.076

Figure 22 Case which OGIP of South East Gala is 0.07
high pressure compartment into low pressure compartment.

On the other hand in two tanks model, Tank 2 as a wet gas reservoir with water influx has OGIP 0.065, so recovery factor has 0.90, and this recovery factor is too high for reservoir with water influx if it is compared with recovery factor in Appendix B. In Appendix B, recovery factor for South East Gala Reservoir is resulted by estimating residual gas saturation using correlation and laboratory data.

CONCLUSION
1. Gala is a retrograde gas reservoir but it can be treated as a wet gas reservoir.
2. Based on Geological Analysis and Tank Model Analysis, South East Gala and West Gala might be 1 tank with water influx and leaking fault or 2 tanks.
3. Reservoir Model for Gala Reservoir as 2 tanks
   West Gala Reservoir Drive Mechanisms are fluid expansion, and PV compressibility;
   South East Gala Reservoir Drive Mechanisms are fluid expansion, PV compressibility, and water influx.
4. OGIP of two tanks is 0.92 and OGIP of one tank with leaking-fault-and-water-influx between 0.94 and 0.95.
5. The best model reservoir for Gala Reservoir is one tank with leaking-fault-and-water-influx based on my study.

ACKNOWLEDGEMENT
I thank to ConocoPhillips for permission to publish this paper. And special thanks to ConocoPhillips Indonesia Exploration Division in Jakarta and Bandung Institute of Technology for excellent supporting.

REFERENCE
7. ConocoPhillips Indonesia Files.
APPENDIX A
TANK MODEL CALCULATION

1. Pressure Corrected

\[ P_{\text{corrected}} = \text{Pressure Gauge @ datum} - \text{Pressure Gauge @ d} + (\text{datum-d}) \text{ gas gradient} \]

Gas gradient is calculated from RFT (Repeat Formation Testing) data which is plotted plot between pressure vs depth and the linear trend line will be gotten. And the slope is gas gradient.

2. Z Calculation

Fluid Properties

Cragoe’s Equation for calculating Mo:

\[ Mo = \frac{6084}{\text{API} - 5.9} \]

\[ \gamma_{\text{gond}} = \frac{141.5}{\text{API} + 131.5} \]

\[ \gamma_{\text{Gmix}} = \gamma_{\text{Ggas}} + \frac{4584(\text{condensate yield})10^4(\gamma_{\text{cond}})}{1 + 132800(\text{condensate yield})10^4(\gamma_{\text{cond}}/Mo)} \]

Because correlation is in Hydrocarbon condition, we calculate \( \gamma_{\text{HC}} \) from \( \gamma_{\text{mix}} \):

\[ \gamma_{\text{GHC}} = \frac{\% \text{moleN}_2(28.01) + \% \text{moleCO}_2(44.01) + \% \text{moleH}_2S(34.08)\)}{1 - \% \text{moleN}_2 - \% \text{moleCO}_2 - \% \text{moleH}_2S} \times 28.96 \]

Sutton’s equation

\[ T_{\text{pHC}} = 169.2 + 349.5\gamma_{\text{GHC}} - 74\gamma_{\text{GHC}}^2 \]

\[ P_{\text{pHC}} = 756.8 - 131\gamma_{\text{GHC}} - 3.6\gamma_{\text{GHC}}^2 \]
H₂O mole calculation (McKetta And Wehe):

\[ A_g = \frac{1 + (\gamma_{Gmix} - 0.55)}{(15500\gamma_{Gmix}T_{res}^{-1.446} - 18300T_{res}^{-1.288})} \]

\[ A_s = 1 - 0.0000000392(\text{salinity})^{1.44} \]

\[ \ln Y_0w = \frac{0.052777P_{res} + 142.3\ln(T_{res}) - 9625}{(T_{res} + 460) - 1.117\ln(P_{res}) - 0.0000000392(\text{salinity})^{1.44}} \]

\[ Y_0w = e^{\ln Y_0w} \]

\[ \text{moleH}_2\text{O} = Y_w = A_g(A_s)(Y_0w) \]

\[ T_{pcmix} = (1 - \%\text{moleN}_2 - \%\text{moleCO}_2 - \%\text{moleH}_2\text{S} - \%\text{moleH}_2\text{O})T_{pcHC} + \%\text{moleN}_2(227.29) + \%\text{moleCO}_2(547.57) + \%\text{moleH}_2\text{S}(672.37) + (\text{moleH}_2\text{O})(1165.27) \]

\[ P_{pcmix} = (1 - \%\text{moleN}_2 - \%\text{moleCO}_2 - \%\text{moleH}_2\text{S} - \%\text{moleH}_2\text{O})P_{pcHC} + \%\text{moleN}_2(493) + \%\text{moleCO}_2(1071) + \%\text{moleH}_2\text{S}(1306) + (\text{moleH}_2\text{O})(3208) \]

The Wichert-Aziz Correction Method:

\[ \epsilon = 120\left( (\%\text{moleCO}_2 + \%\text{moleH}_2\text{S})^{0.9} + (\%\text{moleCO}_2 + \%\text{moleH}_2\text{S})^{1.4} \right) + 15(\%\text{moleH}_2\text{S}^{0.5} - \%\text{moleH}_2\text{S}^{1}) \]

\[ T_{pc} = T_{pcmix} - \epsilon \]

\[ P_{pc} = \frac{P_{pcmix}(T_{pcmix} - \epsilon)}{T_{pcmix} + \%\text{moleH}_2\text{S}(1 - \%\text{moleH}_2\text{S})\epsilon} \]

\[ T_{pr} = \frac{T_{res} + 460}{T_{pc}} \]
\[ P_{pr} = \frac{P_{m}}{P_{pc}} \quad P_{pr\text{initial}} = \frac{P_{m\text{initial}}}{P_{pc}} \]

Z factor coefficients: (Brill and Beggs correlation)

\[ A = 1.39(T_{pr} - 0.92)^{0.5} - 0.36T_{pr} - 0.101 \]

\[ B = (0.62 - 0.23T_{pr})P_{pr} + \left( \frac{0.066}{(T_{pr} - 0.86) - 0.037} \right)P_{pr}^2 + \left( \frac{0.32}{10^{0.001T_{pr}}} \right)P_{pr}^6 \]

\[ B_{\text{initial}} = (0.62 - 0.23T_{pr})P_{\text{pr\text{initial}}} + \left( \frac{0.066}{(T_{pr} - 0.86) - 0.037} \right)P_{\text{pr\text{initial}}}^2 + \left( \frac{0.32}{10^{0.001T_{pr}}} \right)P_{\text{pr\text{initial}}}^6 \]

\[ C = 0.132 - 0.32 \log(T_{pr}) \]

\[ D = 10^{0.3106 - 0.4T_{pr} - 0.1824T_{pr}^3} \]

\[ z = A + \left( 1 - A \right) \exp^{B_{\text{initial}}} + C(P_{\text{pr\text{initial}}})^D \]

3. P/Z calculation

\[ \frac{p}{Z} = \frac{P_{\text{corrected}}}{Z} \]

4. Gas Produced Calculation

Total Gas Produced = Gas Produced + water equivalent + condensate equivalent

Where

- water equivalent = \( WE \)
- condensate equivalent = \( CE \)

Water And Condensate To Gas Equivalent

The produced liquid is converted to its gas equivalent, assuming it behaves as an ideal gas when vaporized in the produced gas (at same condition, the same volume gas means the same mole).

Taking 14.7 psia and 60°F as standard condition,

\[ V = \frac{RT_{sc}}{P_{sc}} = \frac{10.73(520)}{14.7} = 379.5646 \approx 380 \text{ cu ft/lbmole} \]

The gas equivalent of one stock tank barrel of condensate liquid is:

\[ CE = Q_o \left( \frac{1}{\rho_{\text{condensate}}} \right) \frac{1}{\text{Mol lb / lbmole}} \]

\[ CE = Q_o (\gamma_a 350 \text{ppb}) \left( \frac{1}{\text{Mol lb / lbmole}} \right) = 133,000 (Q_o \gamma_a) \frac{1}{\text{Mol lb / lbmole}} \]

The gas equivalent of one stock tank barrel of water is:

\[ WE = Q_w \left( \frac{1}{\rho_w} \right) \frac{1}{\text{Mol lb / lbmole}} \]

\[ WE = Q_w \left( \frac{1}{M_w} \right) \frac{1}{\text{Mol lb / lbmole}} \]
WE = $Q_w (350 \text{ppb}) \frac{1}{18 \text{ lb/}}{\text{lb/mole}} (380 \text{cuft/}}{\text{l/mole}} = 7388.8889Q_w = 7390Q_w$

So, Total Gas Produced is

\[ \text{Total Gas Produced} = Q_g + \text{WE} + \text{CE} = Q_g + 7390Q_w + \frac{133,000(Q_w \gamma_o)}{M_o} \]

And cumulative gas produced is

\[ G_p = \sum Q_{g_i} + 7390Q_{w_i} + \frac{133,000(Q_w \gamma_o)}{M_o} \]

5. Plot p/z as ordinate and and Gp as axis
APPENDIX B
ESTIMATING RESIDUAL GAS SATURATION IN GAS RESERVOIRS WITH WATER INFLUX (SOUTH EAST GALA RESERVOIR)

In Appendix B will be shown estimating residual gas saturation (Sgr) in Gas Reservoirs With Water Influx (South East Gala) using Agarwal’s Correlation\(^4\) and laboratory data.

**Agarwal’s Correlation\(^4\)**

The correlation, based on multiple regression analysis of 320 experimental measurement of imbibitions residual gas saturations. Because porosity of Gala Reservoir is about 20%, Gala Reservoir is assumed as an unconsolidated reservoir.

For unconsolidated sandstones,

\[
S_w = -0.51255987(100S_{gr}) + 0.026097212(10^4 \phi S_{gr}) - 0.26769575(100\phi) + 14.796539
\]

Fluid in Gala Reservoir is assumed gas, and water.

\(S_{wi} = 0.3\)

So,

\(S_{gr} = 1 - 0.3 = 0.7\)

And

\[
S_w = -0.51255987(100(0.7)) + 0.026097212(10^4(0.2)(0.7)) - 0.26769575(100(0.2)) + 14.796539
\]

\(S_w = 0.101\)

So, Recovery Factor (RF) is

\[
RF = \frac{(1-S_{gr} - S_{wi})}{(1-S_{wi})} = \frac{(1-0.101-0.3)}{(1-0.3)} = 0.8557
\]

**Based on Laboratory Data**

Based on SCAL of Gala 2 and 3, average Sgr of Gala Reservoir from imbibitions is about 0.25.

So, Recovery Factor (RF) based on laboratory data is

\[
RF = \frac{(1-S_{gr} - S_{wi})}{(1-S_{wi})} = \frac{(1-0.25-0.3)}{(1-0.3)} = 0.6429
\]