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Evaluation of Remaining Gas Reserves Using the Material Balance Method for Planning Gas Field Development

Dyah Rini Ratnaningsih[1*], A. M. Suranto[1], Cahyadi Julianto[1]
[1] Department of Petroleum Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jl. SWK Ring Road Utara No.104, Ngropoh, Sleman, Specisl Region of Yogyakarta - 55288
*Corresponding Author: rini_diah@yahoo.com

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Abstract

The demand of energy in the world will increase due to the increasing population and industrial activity. Currently, the fossil energy is relatively cheaper compared to other energy sources, especially natural gas. The "CJ" field is a gas field located in the South Sumatra Basin, Indonesia with a reservoir located in the Basalt Telisa Limestone (BTL) formation. This gas field consists of 3 wells namely Well GTA-1, GTA-2, and GTA-3 which produced from 1951 to 1991. In 1991 the three wells were suspended and will be reopened in 2021 due to request from buyers for 10 years. The research method is collecting and consisting of data on reservoir, production, and physical properties of the gas. The next step is to calculate the value of the gas formation volume factor and Z-factor (gas compressibility factor/gas deviation factor) with various pressures. After it, determine the type of drive mechanism using the Cole Plot method (used to differentiate between depletion drive and water drive). After knowing the type of drive mechanism, determine the current OGIP value using the material balance method. If the OGIP value is known, the next calculation is the Recovery Factor (percentage of the amount of gas that can be produced to the surface), Ultimate Recovery (UR) and finally the value of Remaining Reserve (RR). Based on the calculation, the OGIP value obtained by the material balance method with P / Z vs GP plots is 83.46 BSCF, Recovery Factor of 80.22%, Ultimate Recovery of 66.96 BSCF, and remaining gas reserve 15.45 BSCF. The maximum flow rate could be obtained by remaining reserve divided contract period. From these results, the maximum reserve value that can be produced to the surface for 10 years is 4.23 MMSCFD. Therefore "CJ" Field meet the needs of buyer in order to fulfil the requirement number which is only 4 MMSCFD.

INTRODUCTION

It is undeniable that the demand of energy in the world continues to increase. To support this case, the energy reserves must be available in the large quantities (Kober et al., 2020). To days, fossil energy is available quite an abundant and it is cheaper than the other energy resources. The most commonly fossil energy are oil and gas because it could be used either for transportation or industry (Dr. Fatih Birol, 2019).

The price of gas energy is cheaper than oil, so it is important to develop gas reservoirs, and this is proven by the cost of selling gas which is cheaper than the price of oil (Gong, 2020; Litvinenko, 2020). Even though the price is low, natural gas is hardly contained so that it should be directly distributed to consumers after leaving the production well. Gas transportation media from wells to consumers are usually through pipelines (Ikoku, 1984).

The simple way to develop of gas field is using a material balance method. Because this method can calculate the several parameters such as Original Gas in Place (OGIP), Recovery Factor (RF), Ultimate Recovery (UR)

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and Remaining Reserve (RR) (Ahmed, 2005; Amyx et al., 1960; Ikoku, 1984). In fact, the form of material balance development can be said to be the first step in the development of the gas field. The next step can be done by analyzing production data and analyzing well test data to determine the current performance of well production in the field. This next step is useful for planning the stages of gas field production so that gas production can plateau in accordance with the specified time(Ikoku, 1984). The amount of this plateau gas flow rate must be in accordance with the consumer's request for a certain time.

The case study in the making this paper is in the "CJ" Field. In this field the data is taken as quantitative information to calculate gas reserves with material balance. The “CJ” field is a gas field located in the South Sumatra Basin with a reservoir in the Telisa Limestone (BTL) Basalt Formation. The “CJ” gas field has 3 production wells, namely GTA-1, GTA-2, and GTA-3 wells. The three wells start production in different years. GTA-1 well started production on May 7, 1951, GTA-2 well started production on July 1, 1979, and GTA-3 well started production on May 27, 1979. Based on production data, The “CJ” gas field was producing until 1991 after that, both of three wells were suspended. The cumulative production value obtained from the three wells in 1991 was 51.51 BSCF.

Based on the buyer's request, the wells in the “CJ” Field must be reproduced immediately with a production contract of 10 years. It is necessary to prepare gas production for planning the development of the "CJ" Field. Knowing the amount of residual gas reserves that can be produced and the capacity of each well to produce is also necessary. If the estimated potential gas reserves contained in a reservoir are classified large, then planning for the field production stages can be carried out used by performance analysis at the “CJ” Field, both in reservoir and well.

The step in calculating the residual gas reserves is to process the data on the physical properties of the fluid so that the gas formation factor (Bg) and the gas compressibility factor (Z-Factor) are obtained. After calculating these physical properties, then calculate the current OGIP (Original Gas in Place) value. The amount of OGIP value in the reservoir in "CJ" Field uses the material balance method because production activities have been carried out in this field. After the OGIP value is calculated, then calculate the value of the Recovery Factor (RF) in the "CJ" Field. From the results of the RF value, the value of Ultimate Recovery (UR) can be calculated. After the UR value is obtained, the Remaining Reserve (RR) value can be calculated. This RR value can be analyzed to determine the amount of gas that can be produced to the surface for 10 years.

The benefit of this study is to find out the potential of gas wells, especially the remaining reserves in the reservoir. If the remaining reserves in the reservoir can be known, then gas field development can be done with certainty based on the potential available in the field. Planning for gas production stages can be done if the available gas reserves are sufficient to meet consumer targets within a certain period of time. During the 10-year contract period, the required plateau rate is 4 MMSCF. If the "CJ" field meets consumer demand with the development of the existing field only change the choke size, then there is no need for additional wells or production facilities.

LITERATURE REVIEW

- **Gas Compressibility Factor (Z-Factor) and Formation Volume Factor (Bg)**

The gas compressibility factor is also known as the gas deviation factor or Z-factor. Its value reflects how much a real gas deviates from an ideal gas at a given pressure and temperature. There are several methods or correlations that can be used to calculate the value of the Z-factor depending on the assumptions used. One of the correlations that can be used is the Beggs & Brill, (1973). This correlation can produce Z-factor values which are quite accurate for many engineering calculations (Guo & Ghalambor, 2012). The assumption or condition for this correlation is that the pseudoreduced temperature value used is between 1.2 < Tpr < 2.4 (Gunanto et al., 2018). In addition, the assumption of the pseudoreduced pressure value used in this correlation is between 0 < Ppr < 8 (Al-Fatlawi et al., 2017); (Beggs & Brill, 1973)). (Beggs & Brill, 1973) Z-factor correlation is stated as follows (Guo & Ghalambor, 2012; Julianto et al., 2021; Gunanto et al., 2018).

$$A = 1{,}39(\mathrm{Tpr} - 0{,}92)^{0{,}5} - 0{,}36\mathrm{Tpr} - 0{,}1 \tag{1}$$

$$B = \left(0{,}62 - 0{,}23\mathrm{Tpr}\right)\mathrm{Ppr} + \left(\frac{0{,}066}{\mathrm{Tpr} - 0{,}86}\right)\mathrm{Ppr}^2 + \left(\frac{0{,}32\,\mathrm{Ppr}^6}{10^E}\right) \tag{2}$$

$$C = 0{,}132 - 0{,}232\log\left(\mathrm{Tpr}\right) \tag{3}$$

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$$D = 10^{F} \quad (4)$$

$$E = 9(Tpr - 1) \quad (5)$$

$$E = 0{,}3106 - 0{,}49Tpr + 0{,}1824Tpr^{2} \quad (6)$$

$$Z = A + \left(\frac{1 - A}{e^{B}}\right) + C\,Ppr^{D} \quad (7)$$

The gas formation volume factor is the ratio of the volume of a number of gases at reservoir conditions with standard P and T conditions (P = 14.7 psia and T = 520 ºR so that Z = 1).

$$B_{g} = 0{,}02829\ \frac{Z_{r}T_{r}}{P_{r}} \quad (8)$$

- **Reserve Calculation (OGIP, RF, UR and RR)**

Before calculating the reserves, the first step that needs to be done is knowing the type of drive mechanism in the reservoir. In determining the drive mechanism for a gas reservoir, the Cole Plot method can be used. The Cole Plot method is a plot between GpBg / (Bg-Bgi) vs Gp (Ahmed & McKinney, 2005).

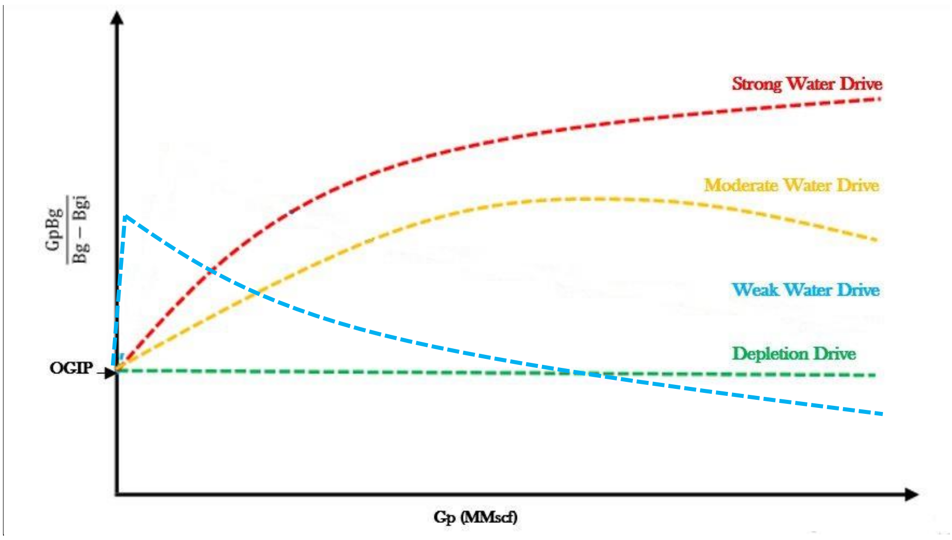

Figure 1. Cole Plot of Several Drive Mechanisms in Gas Reservoir (Ahmed, 2005)

Figure 1 is a plot consisting of several curves representing the type of drive mechanism in the gas reservoir. If the plot between GpBg / (Bg-Bgi) vs Gp produces a green curve, it can be indicated that the type of drive mechanism in the gas reservoir is a depletion drive. In a weak water drive reservoir (blue curve), it always begins with a very sharp increase in cumulative production, and it is also followed by a sharp decrease in the curve instantly. The results of the red and yellow curve plots indicate that the type of drive mechanism in the gas reservoir are strong water drive and moderate water drive, respectively. The plot of GpBg / (Bg-Bgi) vs Gp on a curve with a strong water drive will continue to increase in cumulative gas production, while the depletion drive will tend to be flat (Ahmed, 2005). Based on production performance, it can be determined to identify the drive mechanism for the gas reservoir.

- **Original Gas in Place (OGIP) Calculation**
Calculations using the material balance method are carried out based on changes in reservoir conditions during production. The material balance method requires fluid properties, reservoir and production data. The material balance method can be used to estimate the initial volume of hydrocarbons in place, predict future reservoir behavior, and the recovery of hydrocarbons in various primary drive mechanisms. If the Z-Factor calculation is obtained for the variation in average pressure, than the value (P / Z) is obtained, which is plotted with the cumulative gas production (Gp) (Ahmed, 2006; Gunanto et al., 2018). Plotting between (P / Z) and Gp will give a trendline y = ax + b, the OGIP value can be found with the equation:

$$OGIP = \frac{b}{a} \quad (9)$$

- **Recovery Factor (RF) Calculation**
  The recovery factor is a percentage that represents the amount of hydrocarbons that can be produced on the surface until it reaches its abandonment pressure. The value of the Recovery Factor is a function of the abandonment pressure and the gas formation volume factor (Ikoku, 1984).

$$RF = \left(1 - \left(\frac{Bgi}{Bga}\right)\right) \times 100\% \quad (10)$$

- **Ultimate Recovery (UR) and Remaining Reseve (RR) Calculations**
  Ultimate Recovery (UR) is the number of reserves that can be taken commercially in a reservoir (Ahmed, 2006). The relationship between Estimated Ultimate Recovery (EUR), Original Gas in Place, and Recovery Factor (RF) is as follows:

$$UR = OGIP \times RF \quad (11)$$

  Remaining Reserve is the large number of hydrocarbons that have not been depleted and are still left in the reservoir. By subtracting the Estimated Ultimate Recovery and the amount of hydrocarbons that have been produced (cumulative production gas / Gp) (Gunanto et al., 2018), it is written in the following equation:

$$RR = (OGIP \times RF) - Gp \quad (12)$$

DATA PREPARATION

- **Reservoir and Production Data**
  Reservoir and "CJ" Field production data are required in this process. Reservoir data include reservoir rock characteristics and reservoir conditions. The reservoir pressure in this field is 2675 Psia and the reservoir temperature is 250 ^{o}F. Meanwhile, production data includes production history consisting of cumulative gas production data and pressure drop over time. The decrease in pressure on cumulative production can be seen in Figure 2. Based on the figure below, it can be seen that along with increased cumulative produced gas, reservoir pressure will decrease, not vice versa, because reservoir pressure decline happens due to the lost of fluid volume produced.

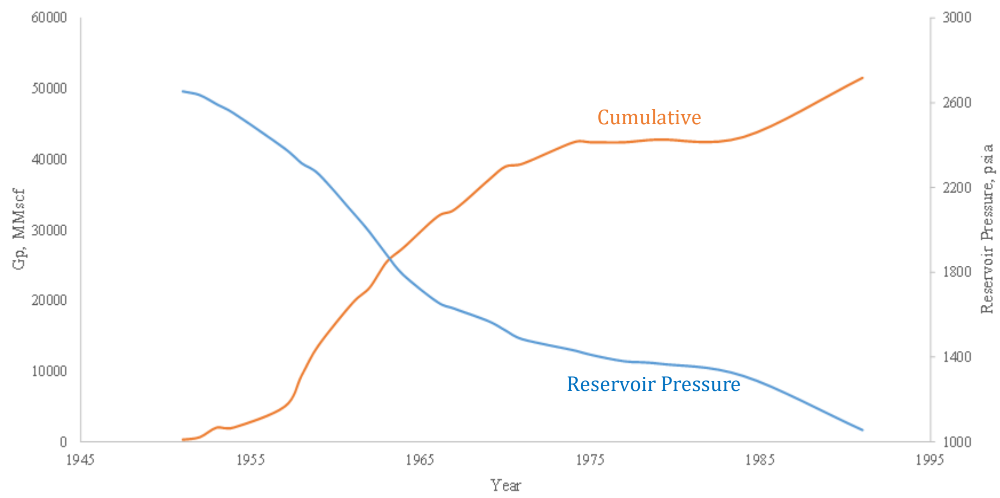

Figure 2. Gas Production History

- **Fluid Properties Data**
  Hydrocarbons in terms of carbon molecular compounds are the number of C atoms that compose them as long as the bonds of carbon molecule compounds are still gaseous. The composition of a gas mixture is expressed as a mole fraction, volume fraction, or fraction by weight of each component (Beggs & Brill,

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1973; Abdassah, 1985). In the standard state hydrocarbon compounds consisting of C bonds from the paraffin series can exist in a gas, liquid and solid state, depending on the number of C atoms in one molecule (Amyx et al., 1960; Ikoku, 1984). Data on the physical properties of gas fluid in the "CJ" Field were obtained based on measurements and tests carried out by obtaining data on the composition of the gas fluid. For the sample data on the physical properties of gas fluxes taken from the GTA-1 well with Specific Gravity (SG) of 0.81 as shown in Table 1.

Table 1. Fluid Components

Components	% Mol
Methane (C1)	76.9%
Ethane (C2)	8.9%
Propane (C3)	6.6%
Isobutane (iC4)	1.0%
n-butane (nC4)	1.5%
Isopentane (iC5)	0.5%
n-pentane (nC5)	0.5%
Hexane-plus (C6+)	2.6%
Hydrogen Sulfide (H2S)	0.7%
Carbon Dioxide (CO2)	0.8%
Total	100%

RESULTS AND DUSCUSSION

The “CJ” gas field has started production since 1951 so that in this field the reserve calculation / OGIP can use the material balance method (Ahmed, 2006). This is because the "CJ" field is already in production, so the calculation of reserves used is the material balance method, although the calculation of the reserves in a volumetric manner has been previously calculated, which is 84.54 BSCF. The steps in calculating reserves with material balance, of course, are influenced by the type of drive mechanism of the reservoir. This type of drive mechanism has a different equation in determining reserves in the next calculation. Determining the type of drive mechanism can be regarded as the first step in determining reserves in the gas reservoir (before determining the OGIP, RF, UR, and RR values).

Gas Compressibility Factor (Z-Factor) and Formation Volume Factor (Bg)

Gas composition data in the reservoir of "CJ" Field is known only from one well, the GTA-1 well. Based on that, the GTA-1 well in the writing of this paper was chosen to be a key well because it has data that can represent the reservoir in the "CJ" Field. As for the gas composition data can be seen in Table 1. From the data on the physical properties of the gas, it can be calculated the value of the compressibility of the gas (Z) and the gas formation volume factor (Bg). Before calculating the Z and Bg values, it is necessary to calculate the Pseudocritical Pressure and Temperature (Ppc and Tpc) (Ikoku, 1984; Guo & Ghalambor, 2012; Beggs & Brill, 1973; Abdassah, 1985).

Table 2. Gas Composition Calculations

Components	% Mol	Yi	Mi	YiMi	Pc	YiPc	Tc	YiTc
C1	0.769	0.769	16.042	12.336	673.10	517.614	343.30	263.998
C2	0.089	0.089	30.068	2.676	708.30	63.039	549.77	48.930
C3	0.066	0.066	44.094	2.910	617.40	40.748	665.95	43.953
iC4	0.01	0.01	58.120	0.581	329.10	3.291	734.65	7.347
nC4	0.015	0.015	58.120	0.872	350.70	5.261	765.31	11.480
iC5	0.005	0.005	72.146	0.361	483.00	2.415	829.80	4.149

nC5	0.005	0.005	72.146	0.361	489.50	2.448	845.60	4.228
C6+	0.026	0.026	107.791	2.803	405.12	10.533	990.86	25.762
H2S	0.007	0.007	34.050	0.238	1306.00	9.142	672.70	4.709
CO2	0.008	0.008	44.010	0.352	1073.00	8.584	548.00	4.384
Total	1	1		23.490		663.074		418.938

Based on the table above, the Ppc value is 663.07 Psia and Tpc is 418.93 R. Because there are gas impurities, it is necessary to correct it so that the corrected Ppc value is 670.79 Psia and Tpc is 419.21 R (Ahmed, 2006). If the Ppc and Tpc corrections are known, then Pseudoreduced Pressure and Temperature (Ppr and Tpr) values will also be obtained. The Ppr value obtained is 3.98 and the Tpr is 1.69. Z and Bg values are obtained based on calculations with variations in pressure drop as shown in the table below.

Table 3. Calculation of Physical Properties of Gas at pressure variations

P (Psia)	Z	Bg (cuft/scf)
14,7	0,99878	1,36038
100	0,99171	0,19856
300	0,97468	0,06505
500	0,95728	0,03833
700	0,93999	0,02689
900	0,92331	0,02054
1100	0,90765	0,01652
1300	0,89338	0,01376
1500	0,88081	0,01176
1700	0,87017	0,01025
1900	0,86163	0,00908
2100	0,85528	0,00815
2300	0,85117	0,00741
2500	0,84929	0,0068
2675	0,84944	0,00636

The calculation of the Z and Bg values in the table above is the basis for determining the type of drive mechanism and the OGIP calculation for the next stage in finding the remaining reserve value. Based on the assumption of pressure drop variation, the values of Z and Bg produce different values for each pressure. The Z value will increase as the pressure value decreases. The Bg value is also the same as the Z value, where the lower the pressure, the higher the Bg value. These Z and Bg values are plotted to determine the type of drive mechanism in the "CJ" Gas Field reservoir.

Determining the Type of Drive Mechanism using the Cole Plot Method

Determination of the type of drive mechanism can have an influence on the calculation of reserves in the "CJ" Field using the material balance method. It is necessary to identify in the "CJ" Field whether the drive mechanism is depletion drive or water drive. The drive mechanism of the water drive itself can be classified as strong, moderate, or weak water drive. If in the "CJ" type the drive mechanism is depletion drive, the method used is P / Z vs Gp (Ikoku, 1984; Ahmed, 2006). Determining the type of drive mechanism using a Cole Plot is done by plotting between GpBg / (Bg-Bgi) vs Gp. The results of calculations for creating a Cole Plot graph can be seen in Figure 3. below.

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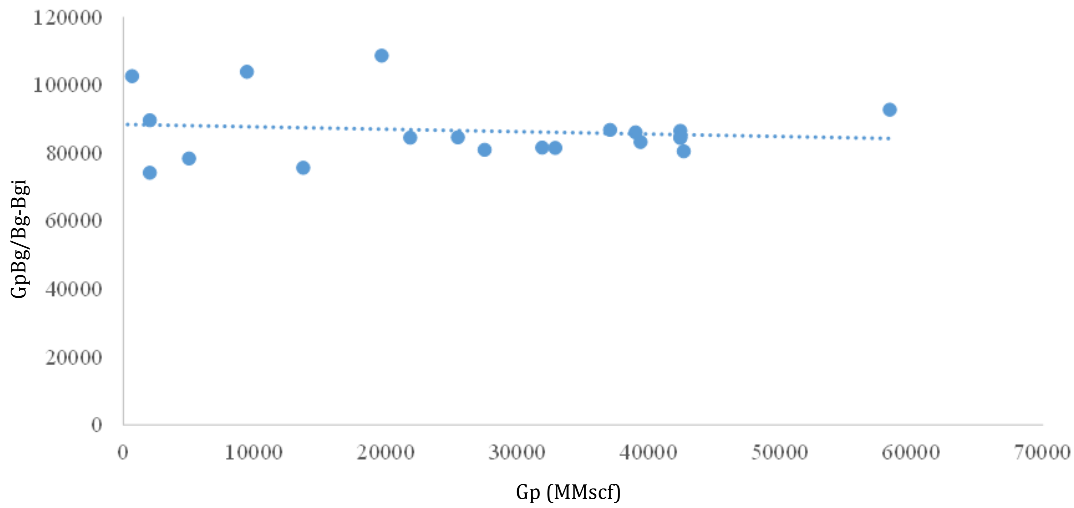

Figure 3. Cole Plot Curve at "CJ" Field

Based on Figure 3, it is obtained that the drive mechanism of the reservoir in the "CJ" Field is the depletion drive reservoir. This is evidenced by the trendline formed from the plot graph between GpBg / Bg-Bgi vs Gp (Figure 1) which tends to be flatter along with the increase in cumulative production in the "CJ" Field.

OGIP (Original Oil in Place) Determination using Material Balance Method with P / Z vs Gp

After the plot between GpBg / Bg-Bgi vs Gp on the Cole Plot, the type of reservoir drive mechanism in the "CJ" field is the depletion drive reservoir so that the calculation of the OGIP value can be done with the P / Z vs GP plot. This method is also used because in the "CJ" field there is no water influx and water production (W = 0). Based on reservoir pressure data, the cumulative gas production, and the gas compressibility factor, the P / Z values are obtained. Based on the results of the P / Z calculation, it can be plotted on a P / Z vs Gp curve. P / Z on the y-axis and Gp on the x-axis so that the OGIP value can be determined (Ahmed, 2006).The results of the graph plot can be seen in Figure 4.

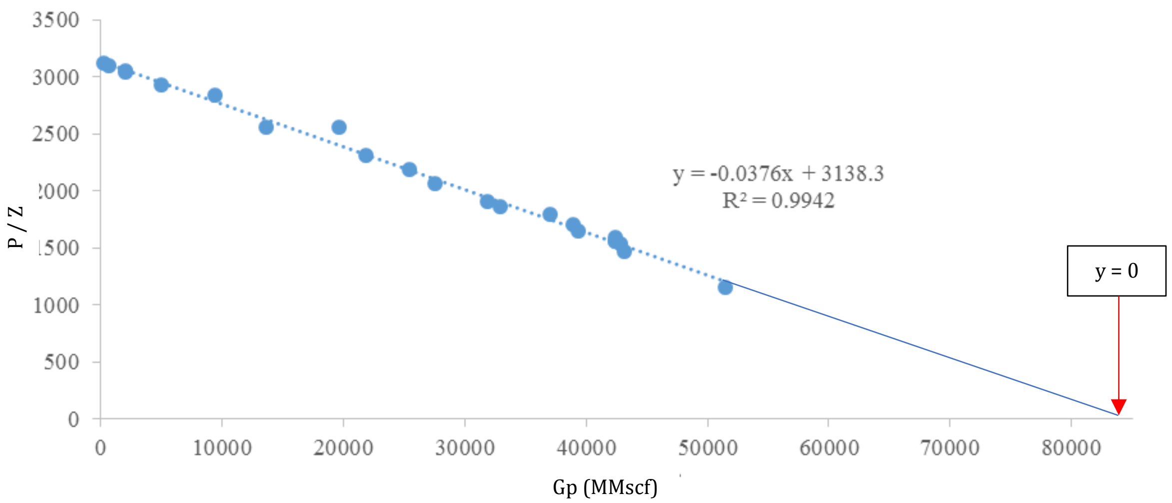

Figure 4. P/Z vs Gp

In Figure 4. the amount of reserve value / OGIP can be determined by drawing the trendline linearly until it intersects or touches the value of Gp on the x-axis. The OGIP value can also be determined through the equation $y = -0.0376x + 3138.3$, it obtained from the trendline which assumes the value of $y = 0$, where the y value is the ratio between the pressure and the compressibility factor of the gas and the x-axis is the cumulative production. The OGIP value can be calculated as follows. Based on the results of the above calculations, the OGIP value is obtained using the P / Z material balance method of 83.46 BSCF. The OGIP value can be said to be quite large. Although the OGIP value is large, this field has been in production for some time so that prospectivity of this field depends on the calculation of other parameters such as RF, UR, and RR.

Recovery Factor (RF) Determination

The Recovery Factor (RF) is the large amount of gas that can be produced from the reservoir to the surface. To determine the RF value, it is necessary to know the abandonment pressure value. This abandonment pressure can later find the value of the gas formation volume factor under abandonment conditions so that the RF value can be calculated. The value of the abandonment pressure in the "CJ" field reservoir can be determined using the assumptions. Based on these assumptions, the abandonment pressure value is obtained from a well depth to pressure where the abandon pressure value is obtained from every 100 Psi / 1000 ft to the well depth (Ikoku, 1984). In the "CJ" field, the depth of the GTA-1 well is 5857.94 ft, the GTA-2 well is 5977.7 ft, and the GTA-3 well is 5892.38 ft so that the well depth can be averaged to 5909.3 ft. Based on the average well depth, the abandonment pressure is 590.93 psia, which is the result of 5909.3 ft multiplied by 100 Psi / 1000 ft. Based on the calculation, the RF value in the "CJ" Field is 80.22%. The RF value becomes the benchmark value to determine the Ultimate Recovery value against the previously determined OGIP value. In addition, the RF value can also be entered in the equation to find the Remaining Reserve value by multiplying the OGIP value and then subtracting the cumulative production value.

Ultimate Recovery (UR) and Remaining Reserve (RR) Determinations

Ultimate recovery is the maximum amount of reserves that can be obtained from the reservoir. The maximum reserve value in the "CJ" Field reservoir is 66.96 BSCF. Remaining reserve is the remainder of hydrocarbon reserves in a reservoir that can still be produced to the surface for a certain time. The "CJ" field has calculated the ultimate recovery amount of 66.96 BSCF and the cumulative production up to September 1991 is 51.51 BSCF. The remaining reserve value can be calculated in "CJ" Field reservoir at 15.45 BSCF.

The "CJ" field is a mature field and will be reproduced after being suspended in 1991. Based on this, it is necessary to evaluate the reserve calculation again to determine the amount of remaining gas reserves. Evaluation of reserve calculation includes calculation of gas in place (OGIP) to remaining reserve. The reserve calculation is done by using the P/Z material balance method because in this field it is indicated that the drive mechanism is the depletion drive reservoir. The determination of the drive mechanism is based on production data obtained from the three wells before it is suspended. This data is still valid for the calculation of reserves after the well will be opened for production again. The results of the calculation of gas in place are obtained through a straight-line formula or equation to the resulting trendline on the curve. Actually, determining the amount of reserves can be done manually by drawing a line until it reaches the abscissa x (y = 0). This is not recommended because if it is done manually the results will be inaccurate. On the curve it is necessary to show the regression value of y as a straight-line substitution equation so that the calculation of reserves will be more accurate and detailed.

The results of the calculation of remaining reserve obtained a value of 15448.75 MMSCF or 15.45 BSCF so that the value of the maximum flow rate of the field "CJ" per day can be calculated for 10 years. The maximum gas flow rate is the rate of gas production that can be produced from the well to the surface within the contract period (years) by considering the remaining reserves in the field with abandonment pressure value of 590.93 psia. So that the maximum flow rate in the "CJ" field can be calculated by a comparison between the remaining reserve value and the length of the contract period in days for 10 years. Based on the results of the calculation of the maximum gas flow rate obtained is 4.23 MMSCFD. The "CJ" Gas Field is considered capable of supplying gas needs to a sales point of or less than 4.23 MMSCFD for 10 years according to the contract period with the buyer.

CONCLUSIONS

Based on the discussion above, it can be concluded as follows:

- The calculation of the residual gas reserves in the "CJ" Field is carried out using the P / Z vs GP material balance method because the drive mechanism in the Basal Telisa Limestone reservoir "CJ" is depletion drive based on the results of the Cole Plot.
- The amount of OGIP value obtained is 83.46 BSCF, the Recovery Factor (RF) is 80.22%, the Ultimate Recovery (UR) obtained is 66.96 BSCF, Remaining Gas Reserve is 15.45 BSCF.
- Based on the remaining gas reseve value obtained, the "CJ" Gas Field is considered capable of supplying gas needs to a sales point of or less than 4.23 MMSCFD for 10 years.

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