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Method to Predict Static Reservoir Pressure of HPHT Onshore Deep Gas Reservoir through WHP Surveillance: Case Study of S Gas Field in South Sumatra

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Abstract

S field is a gas producing field in South Sumatra that has been producing since 2010. It accounts for 100% of the block's gas production. Despite its important role, it only has 4 static bottom-hole pressure data which were acquired during initial well completion in 2004, and CPP shut-down in 2014, 2018, and 2019.

Reservoir pressure data is very important for reserves update, reservoir simulation, surveillance, and forecasting. Reservoir pressure data is typically analyzed from Static Bottom Hole Pressure (SBHP) surveys after the well reach stabilized shut-in pressure. However, there is a multitude of risks and challenges involved in conducting SBHP survey jobs, such as high pressure & temperature (HP/HT), high H_2S content, deep well, production loss, government's approval, and high overall costs.

In order to obtain reservoir pressure data while reducing risk and cost, a method is introduced to get SBHP data from well head pressure (WHP) data during shut-in time by using pressure data correlation during latest SBHP and WHP records. In this case study, the method consists of 4 main steps: (1) Interpolate missing data from SBHP or WHP records; (2) Determine the static pressure period; (3) Plot WHP and SBHP records to determine the suitable correlation; (4) validate correlation with actual data. Three different gas-pressure approaches (pressure, pressure-square, and pseudo-pressure) were used to get the most suitable static BHP correlation.

This paper will discuss the operational challenges, concept & procedure of proposed method, comparison, and validation result of each correlation. This method is proven to be applicable with every gas-pressure approaches with degrees of error less than 2%. In the future, this method can benefit gas field operation & reservoir monitoring activities to be more cost-efficient, with potential savings up to USD 125,000 for each planned SBHP survey job.

Keyword: static reservoir pressure, wellhead pressure, SBHP, HPHT deep gas reservoir, pressure-square, pseudo-pressure

Introduction

As reservoir study & business concern, gas reserve in our reservoir assets should be known and monitored especially by reservoir engineer. One of main data to estimate reserve of gas reservoir is reservoir pressure. This data usually obtained by several method: pressure calculation to datum from data Measurement during bottom-hole survey; extrapolation from pressure decline trend; calculation from reservoir simulation; calculation from material balance; or estimation from correlation/ simplified analytical formula. However, the most reliable & trusted value of data comes from bottom-hole survey (included calculation steps to datum reference). The other methods have a lot uncertainty with different confidence level of data for each method.

In this case, S field as gas producing field has operational issue which made data acquisition by bottom-hole survey limited to only 4 data. Gas reservoir of S field only has less than 3 active wells which either producing all of gas production from this field or P&A wells. So, special permit from management & government must be acquired to shut in well & do bottom-hole survey with business & safety consideration. Due to limited data, other methods to predict and estimate reservoir pressure may not be reliable and trusted. This way that leads 2018 & 2019 bottom hole pressure survey were proposed in the first place. To do survey job, equipment must meet the required specification which are power rating, H_2S proof, and HP/HT rating. S gas reservoir has depth 12,000 ft with side track and open hole completion. With original reservoir pressure more than 8,000 psi, this reservoir was categorized as overpressure reservoir with slightly wet gas but the pressure has depleted in current condition. Previous temperature survey in 2014 show value around 390-400 ^{0}F. H_2S content of this well up to 200 ppm in bleed line (included accumulation of material). At the same time, there are some issues in well head integration (passing valve) which make the operation more risky. Therefore, these challenges increased the specification needs for survey job operation and cost of job (up to USD 125,000 for each job in 2018 and 2019). So some questions pop up from this condition: "Should we keep monitoring of reservoir pressure in this way which high operational risk and high cost? Is there another method to simplified while keep data reliable?"

A new method by using wellhead pressure monitoring and bottom-hole survey was introduced in this study case to make a simply but specified and reliable correlation with limited data. Previously, some researcher has explored this topic. Smith (1950) propose a wellhead to bottom-hole conversion algorithm for dry gas wells in flowing condition by using analytical method. Cullender and smith (1956) developed a widely used procedure to calculate bottom-hole pressures in gas wells which modified by Peffer et al. (1988). all of these methods are limited to only flowing conditions. Charidimos et al. (2013) also proposed analytical modification of Smith (1950) formula to represent a wellhead to bottom-hole conversion algorithm for dry gas wells in static condition by using various assumption as part of wellhead pressure transient analysis study. However, this method can't compromise various condition of wells & reservoir. By using bottom-hole pressure survey and wellhead pressure monitoring data, we can relate correlation between wellhead pressure and static bottom-hole pressure. There are several advantages by be able to derive data from this method. The cost of recording Wellhead data & operational challenges are much cheaper and lower than actual bottom-hole survey job (which usually recorded anyway in most cases of HP/HT gas field). At the same time, we can gain more data to validate reserve and reservoir simulation model for other studies & business issues.

This paper assesses the new method to predict static reservoir pressure as bottom-hole survey substitute and the most suitable pressure system to represent gas pressure in correlation from this method (pressure, pressure square, or pseudo-pressure approach). This method will be presented as work flow so anyone can try and implement the method. Each pressure system will be presented so we can determine which pressure system suit the most.

Data and Method

As stated before, limitations of available data and option made the reservoir study & reserve monitoring not optimal. Before bottom-hole survey in 2018, there are only original reservoir pressure data from flow after flow test & well completion in 2014 and bottom hole pressure & temperature data from bottom hole survey in 2014. Wellhead pressure monitoring & recording during survey bottom-hole survey in 2018 and 2019 were proposed to be implemented for wellhead pressure transient analysis. Fortunately, this well has Continue wellhead pressure monitoring. However, due to problem in well head integration issue, there is secondary build up which cause the build up data for wellhead pressure transient study more tricky and may be not valid. This caused the wellhead pressure data recording left behind. Therefore the idea to utilize this data with our target data (Static bottom-hole pressure from bottom-hole survey) was came.

The idea is simple. Let say All factors which caused deviation from analytical method from previous study, such as H_2S content, side track, HP/HT, and deep well, was categorized as X factor. This X factor will be accounted in our correlation by some relationship between wellhead pressure and bottom-hole pressure in the same time after static condition. After static condition, we can assume the condition between bottom-hole & wellhead was in balance condition (no gas redistribution). Therefore, we can get relationship of bottom-hole pressure as function of wellhead pressure for this well (Eq.1).

$$Pwf = f(Pwh) \quad \text{------------------------} \quad (1)$$

The correlation will be tested by using other pressure data from various year (2010, 2014, 2018, and 2019) to validate the method.

However, there are several method to represent pressure in gas system such as pressure, pressure square and pseudo pressure. In the early period, gas system and properties usually stated in linear pressure relationship. As development goes, Rawlines & Schellhardt (1935) noted that square of average pressure has linear relationship to flow rates if plotted in logarithmic coordinates. This relationship indicates that pressure in gas system can be represented with pressure square. However, it is only valid for medium-to-low pressure ranges. As study of this phenomenon developed, Al-Hussainy et al (1966) developed concept of pseudo-pressure (Ψ) to deal with gas properties (gas compressibility factor (Z) and gas viscosity (μ)) changes due to pressure dependent (Eq.2):

$$\varphi(p) = 2\int_0^p \frac{pdp}{\mu Z} \text{ --------------------- (2)}$$

All of this representing system of gas pressure still commonly found and used in these days. so not only this method & idea will be tested based on the error margin over time, but the best pressure system to represent it will be tested too. After that, we will compare it with modification of smith formula by Charidimos et al. (2013) which are (Eq.3 – Eq.5):

$$Pwh^2 = Pwf^2K_s - K_f \text{ --------------------- (3)}$$

$$K_s = e^{-S} \text{ ---------------------------------- (4)}$$

$$S = \frac{0.0683\gamma_g L}{(zT)_{average}} \text{ --------------------------- (5)}$$

Where K_s and K_f represent gravity forces factor and friction losses factor respectively. In their study, assumption of no friction losses due to no flow condition was used and make the formula become (Eq.6):

$$Pwf = Pwh\sqrt{\frac{1}{K_s}} \text{ --------------------------- (6)}$$

As stated on their study, the error of this method is less than 2%. This value not only will be tested in this study, but also will be limit of error for this method.

In this case we will used data of bottom-hole survey in 2018 as basis of our study. From survey job & wellhead pressure recording, the results are presented in figures 1 & 2:

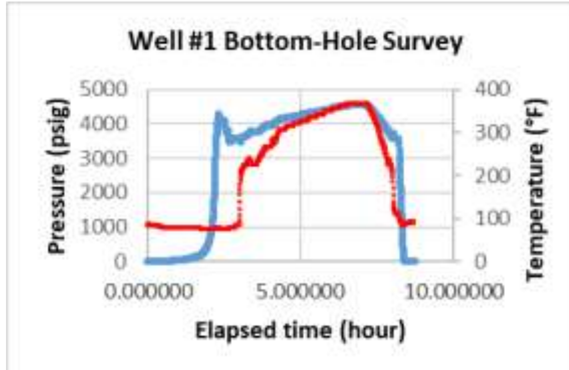

Figure 1: Well #1 S gas field Bottom-hole survey chart

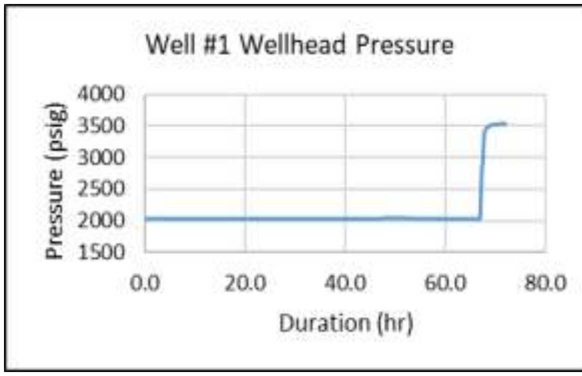

Figure 2: Well #1 S gas field wellhead pressure recording.

Red line and blue line represent temperature and pressure respectively. This survey was done by top-down method but only up to 10,400 ft KBMD due to risk of equipment failure if equipment reach water level in bottom-hole. The result showed static bottom-hole pressure at 10,400 ft KBMD of this well is around 4,500 psi with temperature 350 ^{0}F. Recorded wellhead pressure during static condition is 3,500 psi. both of them have different start time of data acquisition but parallel.

These data will be processed by using the new method. The steps of procedure for this method are (Figure 3):

1. Collect / prepare wellhead pressure recording and bottom-hole pressure survey data.
2. Make sure the data has correct level reference (wellhead pressure on surface level and bottom-hole pressure on middle of reservoir perforation). If not, interpolate or extrapolate data to level reference with reliable support data.
3. Make sure wellhead pressure & bottom hole pressure during static condition have same time reference. If not, interpolate or extrapolate data to time reference with reliable support data.
4. Determine pressure system that will be used and calculate pressure representation (if any);
5. Plot wellhead pressure and bottom-hole pressure (in chosen pressure system) in cartesian plot;
6. Define relationship of bottom-hole pressure as function of wellhead pressure (linear or logarithmic function).
7. Check absolute error. Use historical data as benchmarking data.
8. If error is higher than error limit, use different pressure system and replot the data.
9. If error is less than error limit, the correlation can be used to predict static reservoir pressure.
10. Calculate static reservoir pressure by converting static bottom-hole pressure to reservoir datum reference.

For step (2), we need to converting data to standard level reference. Actually, we can correlate pressure from any level reference to pressure from other level reference (for example from depth 500 ft KBMD to 3000 ft KBMD which is not reservoir depth). However, we still need converting this data to middle of reservoir perforation to be able called the data as static bottom-hole pressure. At the same time, there will be reliability bias due to different value of data acquisition at different level of depth if there is no standard level reference in this method. So, bottom-hole pressure at middle of reservoir perforation & wellhead pressure will be used as standard of level reference. Fluid gradient can be used as data support. For step (3), we need use same time reference for both of the data to make sure the correlation will not be a function of time.

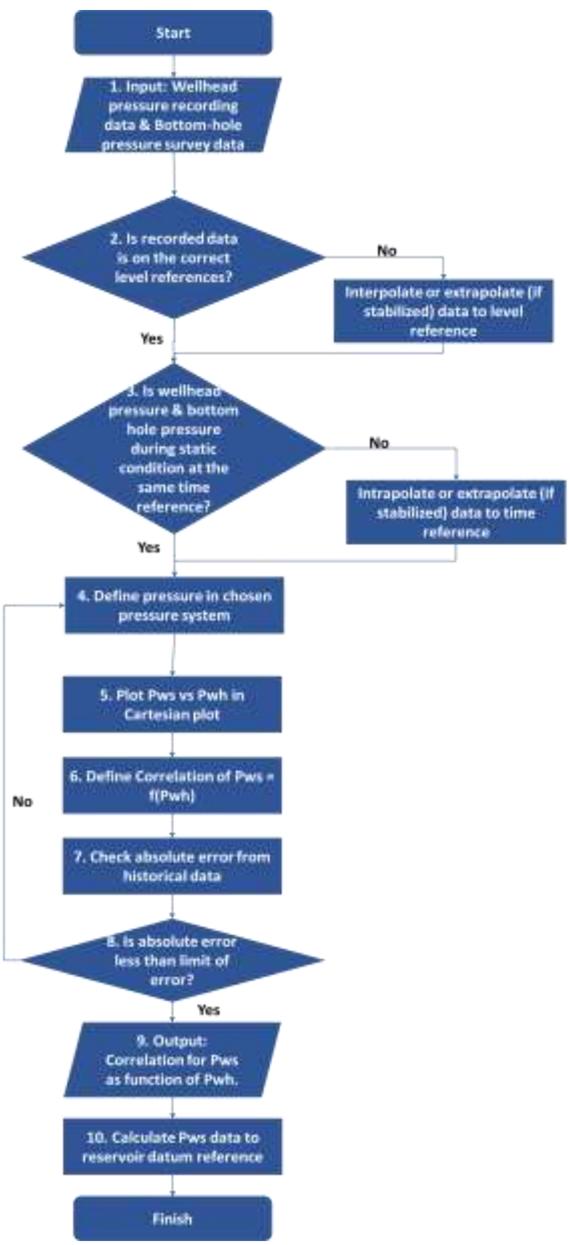

Figure 3: Flowchart of Method to predict static reservoir pressure through WHP surveillance

Result and Discussion

In this case, the data has been converted to level reference (pressure data from 10,400 ft KBMD converted to 12,000 ft KBMD) by using fluid gradient. The data also has been converted to same time reference due to different start time of recording and different interval time of data acquisition from each equipment (digital wellhead pressure gauge and Electric Memory Recorder). In this case, combinations between each pressure system (pressure, pressure squared, and pseudo-pressure) and relationship function (linear or logarithmic) were used to study the best approach to represent correlation & gas system in this method. Each of them is used to predict static bottom-hole pressure from wellhead pressure during survey job (2010, 2014, 2018 and 2019). Then, errors are calculated from there. The result for S case are presented in figure 4 & figure 5.

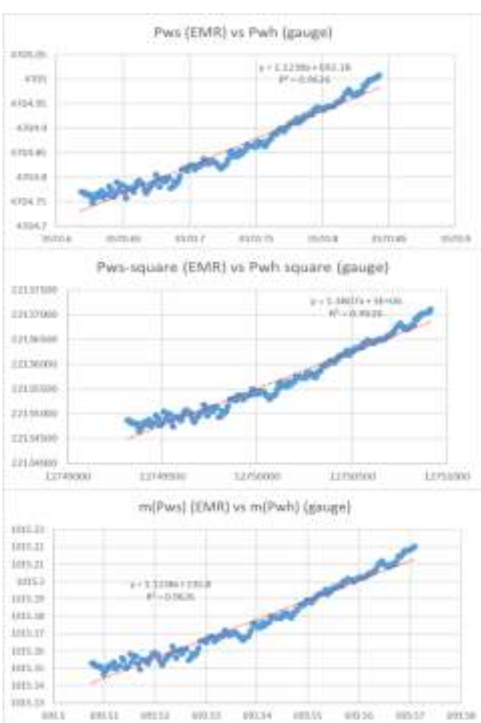

Figure 4: Plot of wellhead pressure vs bottom-hole pressure for each pressure system in linear function

Figure 4 shows that linear function in can be used in every pressure system and shoe good trend line to represent relationship wellhead pressure & bottom-hole pressure (almost straight line). This phenomenon similar with logarithmic function in every pressure system. However, errors of linear function (either pressure, pressure square, pseudo pressure approach) are lower than logarithmic function as shown in figure 5. As you can see, error from logarithmic function is increased if the time difference between used basis data for method and the one we would like to predict are bigger. In this case, basis data is from 2018 and the biggest error is shown from 2010. Due to higher value of error than error limit (2%), logarithmic function will not be recommended in this method. For linear function, only linear pressure square has different trend than the others.

Approaches	Year of Data reference	Error (%)
Linear P	2019	0.1995
	2018	0.0085
	2014	0.0202
	2010	1.3208
Logarithmic P	2019	0.3082
	2018	0.0226
	2014	6.3209
	2010	15.3167
Linear P square	2019	0.8184
	2018	0.5751
	2014	0.6066
	2010	0.3084
Logarithmic P square	2019	0.5588
	2018	0.3659
	2014	26.0073
	2010	103.4751
Linear Pseudo-pressure	2019	0.2002
	2018	0.0078
	2014	0.0197
	2010	1.3212
Logarihtmic pseudo-pressure	2019	0.2002
	2018	0.0067
	2014	8.3040
	2010	18.8168

Figure 5: Comparison for each combination of approaches

From figure 5, Linear pressure approach and linear pseudo-pressure approach has similar trend (Prediction data from 2010 has the biggest error) while linear pressure square relatively stable with higher value of error.

Linear pressure square approach has error range 0.31-0.81 % while linear pressure approach and linear pseudo-pressure approach have error range 0.01-1.3% to predict static bottom hole pressure during 9 years of production. Both of them has error lower than By consideration reliability, Linear pressure square is recommended due to relative stable margin of error while keeps error lower than 1%. However, further study are required to look effect of different data basis and consistency of method and conclusion in different field implementation.

By using this method, we can reduce the required amount of bottom-hole survey job for surveillance. We can predict static bottom-hole pressure just by shut in well and measure wellhead pressure after shut in period. Further bottom-hole survey has function to recalibrate correlation after few years (> 10-15 years). There will be huge advantage in risk management & cost efficiency If this method can be implemented in green gas field.

Conclusions

1. The method to predict static bottom hole pressure & static reservoir pressure from WHP surveillance is shown reliable & suitable to be used in gas field especially in S field case.
2. Linear function is better to be used in this method due to lower degree of error than logarithmic function.
3. The most suitable & reliable gas pressure system for this method is pressure square with error range 0.31-0.81 % in this case.
4. In general, error of prediction is increases along time difference between basis data & data we would like to predict.

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