Application hall plot method for surveillance waterflood in oil reservoir

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Abstract. Pattern X is one of the patterns in Field Z which is 60 km west of Prabumulih, South Sumatra, where the full-scale waterflood is implemented. In general, the pattern used is an irregular inverted 5-spot where there are six production wells namely Z-091, Z-098, Z-110, Z-157, Z-195, and Z-233 and one injection well namely Z-227. Waterflood is a secondary recovery method by injecting water into the reservoir. Waterflood surveillance analysis was carried out to determine the conditions around the production and injection wells during waterflood. Surveillance analysis is used as a measure of success in waterflood activities. One of the methods that used is the Hall Plot method. It is obtained a slope which moves upward where displacement is moved normally or stable. However, over time there is an increase in the slope of the tilt where skin changes occur. In fact, the slope that occurs due to the installation of Multilayer Packer is used to adjust the desired injection rate. In the end, the injection results have no problems and run stable.

1. Introduction
Continuous production of oil and gas causes the production rate to decrease and reservoir pressure to decrease which causes oil reserves to remain in the reservoir. The most common secondary recovery method used to improve oil recovery from the reservoir is waterflooding. Factors to be considered in the design and installation of waterflood projects are rock wettability, rock and fluid properties, formation heterogeneity, flood patterns, injection water composition, water injection rate, fluid production rate [1]. Forecasting the rate of injection of water into the reservoir through injection wells is needed so that water injection can improve sweeping efficiency to the remaining oil saturation so it is necessary to monitor the performance of waterflooding [2].

Lyu W has increased the effect of developing waterflooding to prevent water breakthroughs and flooding along natural cracks. The result is that the opening pressure of the natural fracture can be used instead of the formation separation pressure, for the maximum water injection pressure threshold. Its effectiveness has been confirmed by comparing the production performance of two wells [3].

Abbas AGA has conducted research by designing water flooding using CMG to improve oil recovery in suitable pilot areas. The results show that water injection as a (reversed) 5-spot pattern with a 1500 bbl injection rate in the Fula Utara field sector model can increase cumulative oil production from this area to 6 million barrels [4].

Ratnaningsih DR has used the Hall Plot and Derivative Hall method to discuss the performance evaluation of injectors in minimizing problems so that oil recovery can be optimal and planned [5].
Waterflood analysis on Pattern X is done to find out how the formation around the injection well during waterflooding and can determine the success rate of waterflood itself. To determine injection performance and possible problems in the well, Hall Plot was analyzed [6]. In this pattern, a Hall Plot analysis is carried out in which there is one injection well analyzed. The purpose of the Hall Plot analysis is to determine the performance of the injection well and the possible problems in the well. So, it can be concluded later whether the injection well is effective in injecting water or not, and can identify problems with the injection system in terms of water quality and compatibility between injection water and the reservoir.

1.1. Waterflood
The water injection method is used to inject a number of waters into the reservoir through injection wells which are expected to be able to push the remaining fluid in the pores of the rock to exit through the production well. The injection is carried out with the aim of obtaining residual oil which cannot be recovered during primary recovery in secondary recovery. Economically the application of waterflood has the advantage compared to other methods of the second stage, including the availability of abundant water, is relatively easy to inject and can spread in the reservoir, more efficient in suppressing oil [7].

Water flooding must be carried out in a homogeneous saturated oil reservoir that has dimensions that will produce a linear flow [8].

The most common procedure for determining the optimum time to start waterflooding is to calculate [9]:
- Anticipated oil recovery
- Fluid production rates
- Monetary investment
- Availability and quality of the water supply
- Costs of water treatment and pumping equipment
- Costs of maintenance and operation of the water installation facilities
- Costs of drilling new injection wells or converting existing production wells into injectors

1.2. Injection water quality
The quality of injection water is one of the important factors in waterflood success. Nature rarely provides water containing free chemicals and bacteria. The main problem with using water to increase oil production is the reaction of the reservoir and water. Where there could be damage to surface and subsurface equipment by corrosion. Water injection operation aims to inject water into reservoir rocks without blockage or permeability reduction from particulates, oil dispersed, scale formation, bacterial growth, or clay swelling [10].

According to the technology subgroup of the operations and environment task group water produced is water that is returned to the surface through oil or gas wells consisting of natural formation water and returning water injected into the formation (backflow of water) sent into the hole as part of the fracture stimulation process (frac) or recovery operation which improved. The water produced is usually produced for the life of the well [11].

According to the Honeywell [12], through continuous monitoring of water injection performance - and real time can control the injection process:
- Identify conditions of blockage and connection of formations faster and easier
- Monitor before and after breakthrough scenarios using an Enhanced Hall Diagnostic plot
- Track reservoir pressure support
- Track total cumulative water volume and injection time
- Monitor reservoir pressure against water injection from time to time. The results will be more accurate than the injection process for medium and long-term oil which significantly higher recovery.
1.3. Injection water source

The source of injection water includes aquifer and injected water. Other water sources are through injection of water into the reservoir for the purpose of maintaining pressure and secondary recovery. Therefore, in oil production, water can be divided into sweeps, good and bad.

Water wells are each well used for the purpose of providing water for underground injection (increased recovery from oil pools or hydraulic good fracture stimulation). Water source zones can range from shallow quaternary sediments to deep saline aquifers [13].

The following parameters are used to assess the best time for each individual to be converted from primary production to water injection services [14]:

- Measured reservoir stacking pressure measured by closing in production
- The rate of fluid production, cumulative volume, and any change in the rate of decline over time
- Every effect of production disturbance observed with adjacent wells
- Pattern of mass balance and / or estimated oil recovery factor - Reservoir pressure relative to the pressure of bubble point

1.4. Surveillance system

Reservoir management for waterflood is usually done to consider systems from reservoir characteristics such as fluid behavior and reservoirs, wells manufacturing and operations, and fluid processing facilities. These things are interrelated parts and have an integrated system. Reservoir management functions in waterflood are to provide facts, information, and knowledge needed to control operations and to obtain maximum economic recovery from the reservoir. Reservoir monitoring begins with data acquisition from wells and production networks as a driver for evaluating well and reservoir performance, then OGIP / reserve evaluation and finally foundation development, where development options are chosen optimally so that production optimization decisions can be taken [15].

1.5. Hall plot method

Hall plots are routinely used in industry to identify injection performance from production data [16]. Hall plots are plots of cumulative injection pressure against injected cumulative volumes used to analyze injections well over a period of time. The potential changes in good conditions that must be investigated are indicated by changes in plot gradients. The Hall Plot is a general monitoring and monitoring tool in the injection project [17]. For non-damaged or stable radial injection into the matrix system, it will produce a unit slope line. An increase in gradient or slope (upward deviation away from the function of the unit slope) is generally an indication of decreasing injection, while a general reduction in slope generally shows an increase or has increased injection [6].

The typical Hall plot is shown in Figure 1. Early in the life of the injection well, the radius of the water zone will increase with time, causing the upward slope to curve as shown in line a to b. After the process of filling the line b to A shows, stable injection or the injection runs normally. Upward slope increases
generally show positive skin or poor water quality can be seen in line D. A similar slope can occur if well care is designed to increase effective volumetric sweeping. However, in this case, the slope will first increase and then be constant. For line B shows a decreased slope, which indicates that injection is above the parting pressure or negative skin. Injection in the final condition can be verified by running a step-rate test. The slope value which is very low is that line b to C is an indication of the possibility of channeling or injection outside the zone. The Hall method is an alternative to the temporary well test approach. Technically, this is very simple, which is only a plot of time from injection pressure versus cumulative injection. Eventual integration automatically filters out short-term fluctuations. The slope of the plot is interpreted as an indicator of the average well injection [19].

The assumptions inherent in this plot are piston displacement, steady state condition, radial single phase, and single layer flow with reservoir pressure where the pressure is constant. It is also assumed that there is no residual gas saturation in the water and oil zone. This plot can be used to determine reservoir properties such as transmissivity (kh) and others when changing reservoir conditions. This plot is based on the form of Darcy's law, namely:

$$q_w = \frac{0.00708 k_w h(p_w - p_e)}{B_w \mu_w \ln \left( \frac{r_e}{r_{wa}} \right)}$$

Where,

$$r_{wa} = r_w e^{-s}$$

Initially, Hall proposed this plotting method to quantitatively analyze the performance of waterflood injection wells. Hall designed the following approach to eliminate complications from pressure variations and injection rates [20]. Where integration forms equations:

$$\int \Delta p \, dt = \frac{141.2 B_w \mu_w \ln \left( \frac{r_e}{r_{wa}} \right)}{k_w h} w_i$$

Where, \(\Delta p = p_w - p_e\)

Hall plays an integral part in reducing pressure with respect to time versus cumulative injection. Observation of this pressure function plot reveals that if injection wells are stimulated, there should be a slope decrease, and if the well is damaged, the slope will increase. This slope assumes a single-phase flow with only one fluid flow. Based on the slope of the plot, if the skin is known, the transmission can be calculated or vice versa. According to Chan, the plot can be useful for evaluating production efficiency but the plot does not reveal details about the behavior of the reservoir flow. Although, some plots can show reservoir characteristics [21].

2. Methods

In this study, a research methodology will be carried out which includes literature study, preparation of data to be used, wellhead pressure data, the volume of water injection data per day. From these data, it will be made into cumulative and plotted into graphs. The results of the graph are then analyzed to determine the condition of the reservoir after water injection. The result can be seen whether the injection well is usually stable or shows the presence of skin by comparing with the Hall Plot curve theory.

3. Results and discussion

The following are the results of the Hall Plots on the Z-227 injection well by plotting between the cumulative injection and the cumulative head pressure. This analysis is compared with the theory of Hall Plots as shown in Figure 1. Which is the theory of Hall Plots in various conditions. From the
analysis carried out on the Z-227 injection well, it was found that the slope moved upwards indicating that the injection was normal or injection was stable. However, over time there is an increase in slope which indicates the occurrence of skin. This increase in slope actually occurs because of the multilayer packer (MLP) installation used to adjust the planned injection rate, but the slope increase looks like an indication of positive skin seen in figure 2. Two plot results that will strengthen the analysis that Hall Plots in this injection well does not have a problem and the injection runs stable so it is expected to be suitable and can maximize production in this Pattern X well.

![Hall Plot Z-227](image1)

**Figure 2.** Hall plot Z-227.

Because the slope increases dramatically, the plot inspection is carried out closer where the slope looks towards a stable or normal direction which does not indicate the presence of skin. Following is the plot hall after the MLP installation where the stable upward slope shows that the injection has been carried out normally.

![Hall Plot Z-227 After MLP](image2)

**Figure 3.** Hall plot Z-227 after MLP.

In the end, it can be concluded that Hall Plot Z-227, has a stable injection and the effect of increasing slope is the use of mechanical devices intended to adjust production according to the desired by the company.
4. Conclusion
Based on the results of injection analysis and planning Based on the results of Waterflood Surveillance Analysis Using Hall Plots in Pattern X, it can be concluded that the injection in the Z-227 injection well runs normally or stable.

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