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Designing pressure build-up test on heavy oil well by alternating oil viscosity

Designing pressure build-up test on heavy oil well by alternating oil viscosity

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Abstract. Pressure Build Up analyses on a heavy oil well would give an inconclusive result on pressure derivative curves. Some kind of thermal injection should be performed prior to implementing the operation of Pressure Build Up test, where the heat will lower the viscosity of the reservoir fluid. The study was aimed to design a proper well test for N-7 Well using a simulator. Since the Pressure Build Up test was intended to reach radial flow period within shut in time of 100 hours, the viscosity of fluid should be reduced to 24.8 cp or less. Sensitivity of several parameters namely viscosity, permeability, porosity, and shut-in time was conducted in designing Pressure Build Up test. This sensitivity would give various radius of investigation. Furthermore, the study was continued to correlate radius of investigation as a function of the parameters mentioned above.

1. Introduction

N-7 Well is one of some wells located on H-Field in Riau Pronvice, Indonesia which had been drilled to complete the data obtained from the previous wells. Pressure build up (PBU) test will be conducted in N-7 Well to predict reservoir characteristics. However, PBU test may not give any good result because heavy oil contained in it. The heavy oil has a high viscosity which is 1069 cp. Since the viscosity affects the propagation of pressure transient, the pressure builds up test will spend a long period of time. Therefore a thermal injection action must be done into this well before performing PBU test. Thermal injection is applied in order to lower its oil viscosity. The condition would give more applicable PBU test.

The objective of this research is to design a reasonable build up test for N-7 Well. Several data of reservoir rock and fluid were obtained from the neighbor well (N-6 Well), since the location of the well is not far from the N-7 Well. It is only 98.43 feet distance between them. A simulator was used to predict the pressure response during PBU test. Sensitivity tests were performed for several parameters namely viscosity, permeability, porosity, and shut-in time in order to find their effect on radial flow formation as well as on radius of investigation. Besides that, the analyses results were used to find a constant that correlate radius of investigation as a function of time, rock and fluid properties.

2. Literature review

Pressure build up test is basically executed with producing well at a constant rate (q) for a period of time (t_p) to establish a stabilized pressure distribution and then the well is closed [1]. Stabilizing the well at a constant rate before testing is an important part of a pressure build up test. If stabilization is ignored, standard data analysis techniques may provide invalid information about the formation [2]. Analysis is performed at changing pressure response after well is closed. Pressure build up test analysis is conducted to determine the characteristics of reservoir rocks. From the well test analysis, it is obtained information such as permeability and skin factor [3,4].

A buildup curve may be divided into three regions, namely: early-time region (ETR), middle-time region (MTR), and Late-time region (LTR). During early-time region (ETR), a pressure transient (pressure disturbance) is moving through the formation nearest the wellbore. In the ETR, the curve is affected by altered permeability near the wellbore and wellbore storage. This effect must be considered because it can affect the results of PBU tests performed, especially in reservoirs with heavy oil content in it. The duration of the wellbore storage effect can be calculated by the following equation [5].

$$t_{wbs} \cong \frac{170{,}000 C_s e^{(0.14s)}}{kh/\mu} \quad (1)$$

where t_{wbs}, Cs, s, k, h, and μ are the duration of the wellbore storage, wellbore storage constant, skin factor, permeability, formation thickness, and viscosity, respectively.

In middle-time region (MTR), the pressure transient has moved away from the wellbore into the bulk formation. If there are no severe reservoir heterogeneities, flow into or away from a wellbore will follow radial flow lines at a significant distance from the wellbore (In MTR and LTR). In this flow regime, fluids move toward the well from all directions and coverage at the wellbore. At well testing operation, radial flow regime must be reached in order to characterize reservoir better so engineers can predict skin factor, reservoir permeability, reservoir pressure, etc. [5-7].

Pressure transient spreads through the drainage area of the well. The rate at which the pressure disturbance spreads does not depend on the distance to the drainage boundary. During the MTR the rate of bottom hole pressure change and the propagation of pressure transient are determined by the reservoir rock and fluid characteristics such as permeability (k), porosity (ϕ), viscosity (μ), and total compressibility (c_t). While, in late-time region (LTR), the pressure transient has reached the well drainage boundaries. The arrival of the pressure disturbance at the drainage boundary marks the end of the transient state and the beginning of the pseudo steady state. Naturally, the change from transient state to pseudo steady state does not occur instantaneously. It actually takes a few seconds in the case of a well located at the center of a circular drainage area, and it takes longer for other shapes. This short period of time which separates the early transient state from pseudo steady state is called the late transient [8].

The radius of investigation (r_i) of a given test is the effective distance traveled by the pressure transients, as measured from the tested well. Radius of investigation values depends on pressure transient signal velocity to pass through reservoir rock. Pressure transient speed is basically influenced by the physical properties of the fluid and the reservoir rock itself. As time (Δt) increases, more of the reservoir is influenced by the well and the radius of investigation increases as given by Ahmed and Meehan [7]:

$$r_i = \sqrt{\frac{k\Delta t}{a\phi\mu c_t}} \quad (2)$$

where a is a constant. The analysis of a pressure builds up test design is performed during transient period.

Modern analysis has been greatly improved by derivative plot which was introduced by Bourdet, Whittle, and Pirard [9,10]. The derivative plot provides a simultaneous presentation of log Δp versus log Δt and Δt log dp/dt versus log Δt, as shown in Figure 1. The advantage of the derivative plot is that it is able to display in a single graph many separate characteristics [11].

3. Method

The data of well and reservoir rock and fluid proterties were collected from the previous well such as where well radius (r_w), formation or reservoir thickness (h), compressibility (c_t), wellbore storage coefficient (C), formation volume factor of oil (B_o), and reservoir pressure (p_r) as listed in Table 1. While, other variables were assumed such as skin factor (s), producing time (t_p), shut-in time (Δt), and flow rate (q).

Table 1. Well and reservoir data.

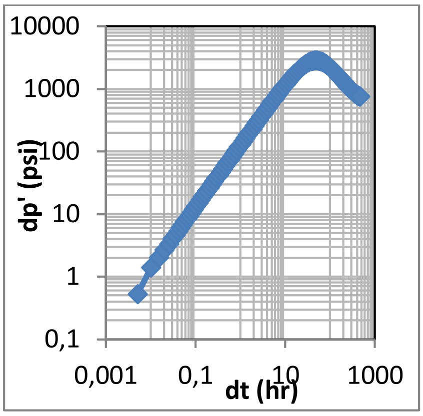
Parameters	Values	Parameters	Values
r_w	0.3 ft	s	2
h	19 ft	p_r	292 psi
ϕ	0.18	kh	7600 mD ft
B_o	1.124bbl/STB	q_p	50 STB/D
μ	1069 cp	t_p	20 hrs
c_t	4.41E-6 psi^{-1}	Δt_1	100 hrs
C	0.01 bbl/psi	Δt_2	500 hrs

Ecrin v.4.0.2 simulator was used to predict the pressure response during PBU test. 450 sensitivity tests were performed for several parameters namely viscosity, permeability, porosity, and shut-in time in order to find their effect on radial flow formation as well as on radius of investigation (radius of pressure transient propagation). Based on the simulation results, the effect of oil viscosity on the radial flow formation and the effect of the several parameters (permeability, porosity, viscosity, and shut in time) on radius of investigation were analysed. In addition, the simulation results were used to find a constant that correlate radius of investigation as a function of time, rock and fluid properties.

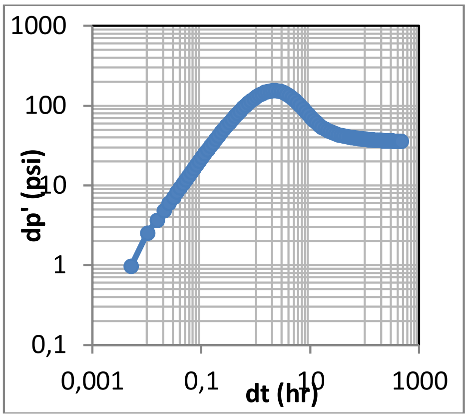
4. Results and discussion

At shut in time of 100 hours, the simulation of PBU test at N-7 Well using parameters stated in Table 1 produced the Pressure Derivative curve. The radius of investigation (r_i) value obtained from the simulation is 198 ft. The simulation was then extended by setting a shut in time of 500 hours. The simulation result is indicated in Figure 1(a). The radius of investigation of the simulation was 440 ft. However, based on the figure, the radial flow period was still not formed. The PBU test design was intended to achieve a radial flow regime before the pressure transient reached the boundary. The condition may be attained by reducing wellbore storage period. Based on Equation (1), in order to shorten the period of wellbore storage, the oil viscosity must be reduced. Therefore, some kind of thermal injection should be performed prior to implementing the application of PBU test operation, where the heat will lower the viscosity of the reservoir fluid. Figure 1(b) shows the simulation result of PBU test using oil viscosity of 66.5 cp and shut in time of 500 hours. The figure indicates that radial flow regime has been established after about 265 hours. Simulation was also conducted for shut in time of 100 hours. In this case, radial flow regime was attained by reducing oil viscosity to 24.8 cp as shown in Figure 1(c). The figure indicates that radial flow regime has been established after about 65 hours. The radius of investigation of the simulation was 1300 ft. This means that viscosity affects both wellbore storage period and radius of investigation.

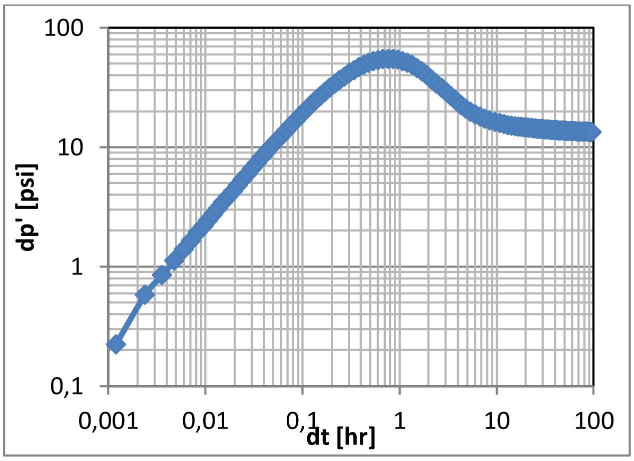
In order to determine the relationship between viscosity and temperature at the reservoir pressure, laboratory tests on heavy oil samples obtained from N-6 wells were carried out to measure viscosity and depicted in Figure 2. Based on laboratory tests that had been done using fluid sample from N-6 Well, a correlation between viscosity and temperature was obtained. The correlation was then used to determine the viscosity for a temperature interval from 150 to 350 ^{o}F that was applied in designing PBU test for N-7. The viscosity values which were calculated using the correlation as indicated in Table 2.



(a). μ = 1069 cp; Δt = 500 hrs



(b). μ = 66.5 cp; Δt = 500 hrs.



(c). μ = 24.8 cp; Δt = 100 hrs.

Figure 1. Effect of viscosity and shut in time on pressure derivative curve.

Porosity sensitivity test interval was determined based on the high porosity value frequency which ranging from 0.15 to 0.25. Then the sensitivity test with porosity parameters was carried out with a value of 0.15, 0.18, 0.20, 0.23, and 0.25 as shown in Figure 3. Using the same data source, Permeability sensitivity interval was chosen based on reservoir rock heterogeneity data which showed the frequency of permeability values. The most permeability values were located between 100 and 1000 mD. Then the sensitivity test with permeability parameters was carried out with a value of 200 mD, 400 mD, 600 mD, 800 mD, and 1000 mD as shown in Figure 4.

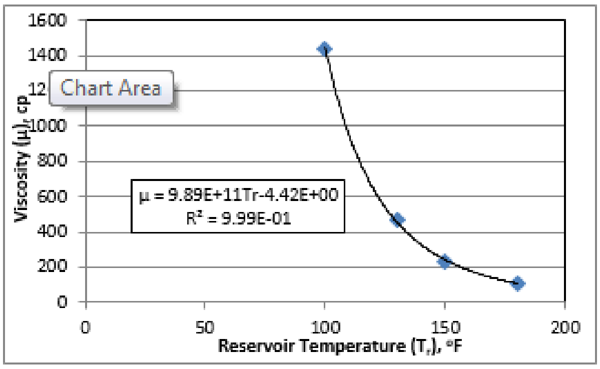


Figure 2. N-6 Well fluid laboratory test.

Table 2. Viscosity values after thermal injection.

T_r, °F	μ, cp
150	237.3
200	66.5
250	24.8
300	11.1
350	5.6

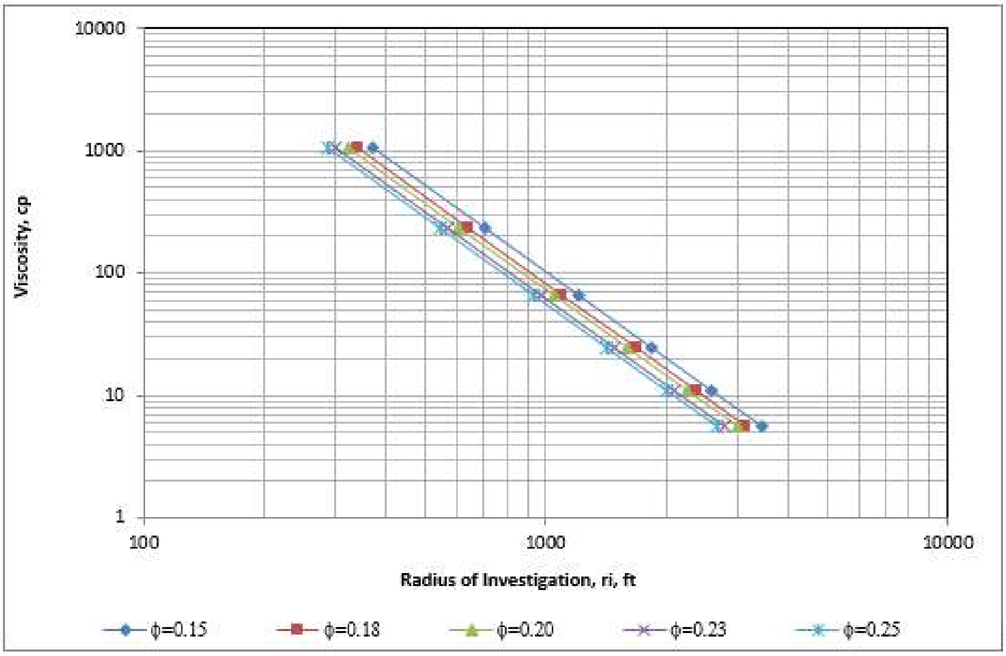


Figure 3. The effect of porosity and viscosity on radius of investigation r_i.

Sensitivity tests were performed to analyse the effect of viscosity and porosity parameters on the radius of investigation (r_i) value and gave the results as shown in Figure 3. From the figure, it can be seen that the effect of porosity as well as that of viscosity is inversely proportional to radius of investigation. Figure 3 shows that the higher the value of porosity fixed, the smaller the value of the radius of investigation obtained. This can happen because if the porosity is greater, there will be more fluid volume contained in a reservoir rock. The pressure transient takes a longer time to pass the fluid filled pore volume if the porosity is higher, since it propagates from molecule to molecule of fluid.

Viscosity is strongly related to the mobility of fluid. The decrease of viscosity is not only to cause the increase of investigation radius (Figure 3), but also to reduce the duration of wellbore storage effect (Figure 1).

Figure 4 shows the effect of permeability and viscosity effect on the radius of investigation value. The figure indicates that the greater permeability is able to propagate pressure transient signal faster. This is in line with the effect of permeability on fluid flow in porous media, where the permeability is directly proportional to the mobility of fluid. Figures 3 and 4 show that the effect of viscosity at various porosity and permeability result in curves with a similar slope on log-log plot.

The radial flow regime must be achieved before the pressure transient reaches the reservoir boundary because during the flow regime, various values of reservoir characteristics can be analysed, such as skin value, permeability, average pressure, and others. From the data in Table 3, it can be seen that for shut-in time of 100 hours, radial flow can occur when oil viscosity is reduced to 24.8. While, for shut-in time of 500 hours, radial flow can occur when oil viscosity is reduced to 66.5 cp. As indicated in the table, the duration of radial flow increases as the viscosity decreases.

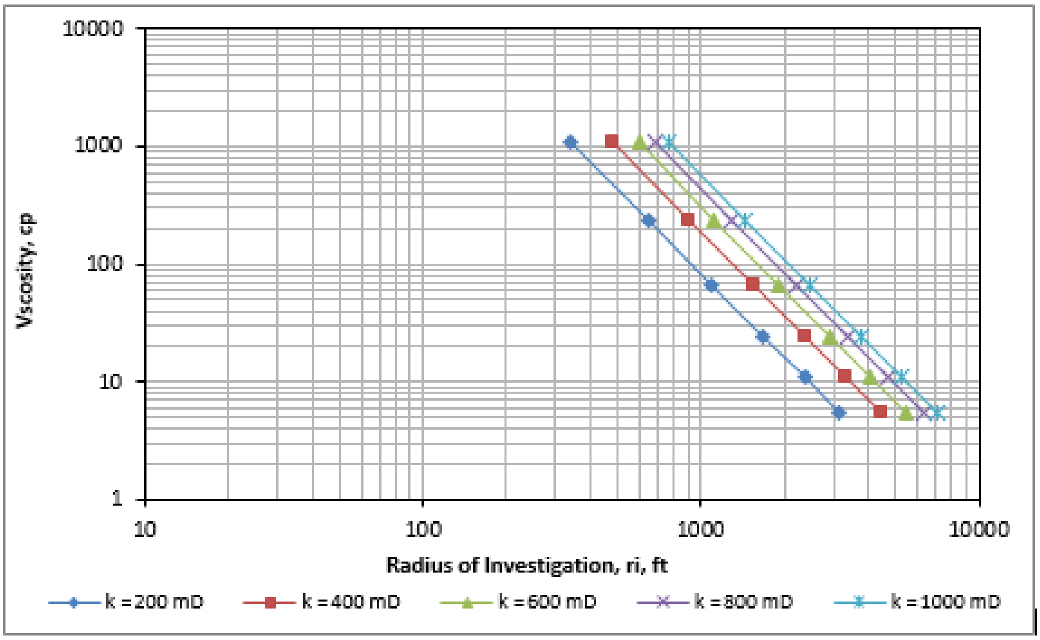


Figure 4. The effect of permeability and viscosity on radius of investigation r_i.

Figure 5 and Table 3 show the effect of shut-in time (Δt) and viscosity on radius of investigation. They show the shut-in time of 500 hours is required to allow the pressure transient propagate to the nearest reservoir boundary (407 ft) from N-7 well for the existing oil viscosity (1069 cp) in the reservoir. The length of shut-in time can be reduced to 100 hours to allow the pressure transient arrives at the boundary if the viscosity of fluid can be decreased to 66.5 cp or less.

The constant (a) in Equation (2) was determined for this study. This value was obtained by plotting the values of investigation radius obtained from the simulator and $\sqrt{(kt/\phi\mu c_t)}$ which produced a straight line as shown in Figure 6. The constant (a) was the slope of the line which was equal to 1197.In order to validate the modified constant value (a), the radius of investigation values calculated by the equation were compared with those obtained from the simulator for several cases as shown in Table 4. The table shows that equation has a good agreement to simulator where the maximum difference is less than 0.4%.

Table 3. Radial flow determination at PBU test scenarios.

μ, cp	Shut in Time, Δt=100 hrs		Shut in Time, Δt= 500 hrs	
	r_i, ft	Δt radial flow, hrs	r_i, ft	Δt radial flow, hrs
1069	198	-	440	-
237.3	419	-	934	-
66.5	792	-	1760	235
24.8	1300	35	2890	303
11.1	1940	57	4320	402
5.6	2730	72	6080	467

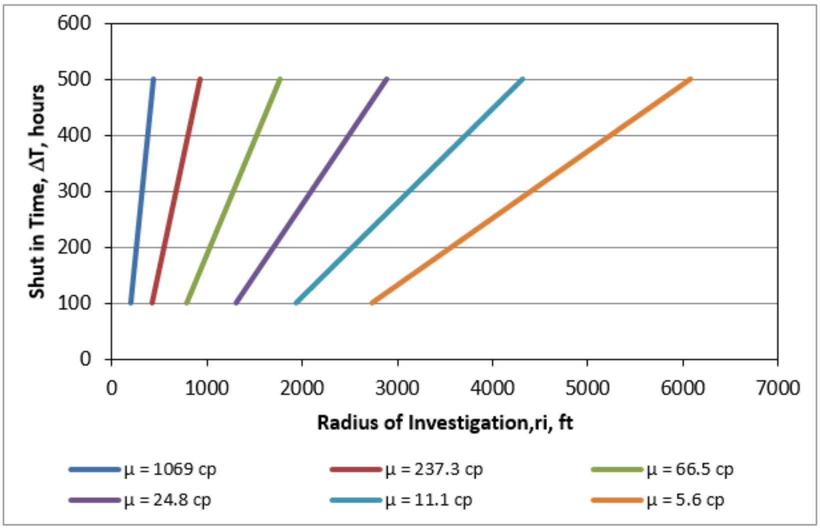


Figure 5. Sensitivity test results of shut-in time vs. r_i.

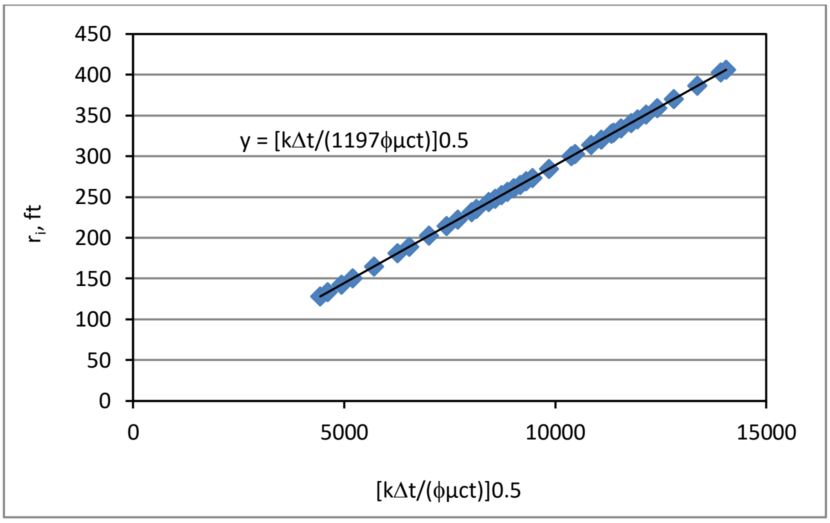


Figure 6. Plot of r_i vs. $[k\Delta t/(\phi\mu c_t)]^{0.5}$.

Table 4. Validation for modified constant value.

$(kt/\phi\mu c_t)^{0.5}$	r_i equation, ft	r_i simu-lator ft	Δr_i, %
x	$y=(1/1197)^{0.5}x$		
12540.363	362.417	361	0.391
10633.958	307.322	308	0.221
11129.304	321.637	321	0.198
8719.062	251.981	251	0.389
10276.407	296.989	297	0.004

5. Conclusions
Based on the simulation results and analyses shown above, several statements are made as follows. The effect of viscosity is not only to cause the propagation of pressure transient (radius of investigation), but also to the duration of wellbore storage effect. Since the pressure build up test was intended to reach radial flow period within shut in time of 100 hours, the fluid viscosity should be reduced to 24.8 cp or less. When shut-in time was extended to 500 hours, then radial flow can be attained by reducing viscosity to 66.5 cp or less. Permeability and shut-in time are directly proportional to radius of investigation. While porosity is inversely proportional to the radius of investigation. A constant value of the correlation of investigation radius obtained from this study was 1197.

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