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EFFECT OF SCALING ON DOWNHOLE PRESSURE TRANSIENT DATA

Susan Petty

Well Production Testing, Inc.
P.O. Box 69
Carlsbad, CA 92008

ABSTRACT

Test data from several wells where scale either formed in the wellbore or in the reservoir have been observed. Some generalizations can be made about the behavior of downhole and wellhead pressure during drawdown and build-up. In addition, estimates of the size of the obstruction can be made in the field. Reservoir parameters can be calculated from pressure build-ups, after the problem of downhole scaling has been identified.

INTRODUCTION

During many long-term test situations in geothermal wells, scale deposits accumulate in the wellbore or in the reservoir. This obstruction to the flow clearly influences test results, as well as causing problems in future production operations. Scale control and clean-up methods are available, but to evaluate the economics of production, we need some idea of the rate of scale build-up, the location of the scale and some estimates of reservoir parameters despite the scale. Since the flow regime in the wellbore is generally two-phase and, in the presence of a rapid change in the size and shape of the flow path, also non-equilibrium, modeling the deposition of scale isn't an easy task. We can, however, use the data collected during long-term tests to evaluate well productivity and make some predictions about rate of scale formation if we collect both downhole and wellhead pressure data. Also, in order to avoid losing or damaging tools used for downhole measurements during production testing, we can make some estimates of the size of the hole remaining in the obstruction.

TEST OBSERVATIONS

Scaling downhole has been observed during several test situations. The most useful data was obtained where both downhole and wellhead pressure were measured. For ease of discussion, scaling is designated as being either in the wellbore or outside the wellbore and, therefore, in the reservoir. Scale in the reservoir may be very close to the wellbore and/or in the liner perforations. Test observations discussed here include three cases:

CASE 1: WELLBORE SCALE - CONSTANT RATE TEST

Scale forms in the wellbore during a constant rate test.

CASE 2: WELLBORE SCALE - FALLING RATE AND PRESSURE

Scale forms in the wellbore during a test where rate and pressure are allowed to drop.

CASE 3: RESERVOIR SCALE - CONSTANT RATE

Scale forms in the reservoir near the wellbore during a constant rate test.

Scale deposition should be most rapid in the zone where flashing occurs, regardless of the type of scale being formed. Initially, the length of the wellbore over which vapor bubbles are nucleating may be short, or if dissolved gases are present, quite long. As pressure draws down in the reservoir, the flash zone will move down the borehole. Thus, wellhead pressure will be the result of the saturation pressure at the reservoir temperature, pressure drops due to frictional losses in the two-phase flow region, head loss due to heat transfer in the borehole, head loss due to the length of the two-phase zone and expansion and vaporization of the fluid as head is reduced. As drawdown in the reservoir slows with time, the flash zone will remain close to the same point in the borehole. When drawdown is rapid, scale will be deposited in a thin layer over a long section of casing. As drawdown slows, scale will begin to build-up into an obstruction which causes a rapid change in borehole diameter. Since the position of the obstruction is keeping up with the flash point, it is reasonable to assume that the fluid eventually is two-phase above the obstruction and a single-phase liquid below it. Observations of scale build-up in surface piping show that scale takes the approximate shape of the flow lines.

CASE 1: WELLBORE SCALE - CONSTANT RATE TEST

When flow rate is controlled and kept constant at the surface, the downhole pressure can be expected to continue to drop as the reservoir pressure drops, despite the increase in size of the obstruction. The wellhead pressure will drop rapidly, however, as the test choke or valve is opened to maintain the flowrate. At some point, the obstruction chokes the flow and the mass flux across the constriction is limited; further reductions in wellhead pressure will not result in increased flow rate and the test will become a falling rate test unless a decision is made to shut-in the well and observe recovery. At this point, the pressure in the reservoir will begin to level out or rise as the choke limits flow rate.

If scale accumulation is very slow and choking does not occur, the wellhead pressure should drop as the scale increases pressure loss due to increased friction in the borehole and decreased size of the borehole. However, these quantities make up less than 10% of the total pressure loss in the borehole and the difference in rate of change of the wellhead pressure compared to downhole pressure may be difficult to detect before a fairly large amount of scale has accumulated. This is particularly true if the reservoir is fractured or if boundaries occur in the reservoir, since these changes may obscure the scale problem until it becomes severe.

CASE 2: WELLBORE SCALE - VARIABLE RATE/PRESSURE TEST

When flow rate is allowed to fall as reservoir pressure drops, the effect of scale build-up in the wellbore will be seen as an increased rate of drop in the wellhead pressure and flow rate. The downhole pressure levels off and finally increases, due to the decreased flow rate. Again, choking will occur when the obstruction is large enough, but before choking occurs, the flow rate will already have begun decreasing more rapidly due to the frictional losses. The wellhead pressure will drop reflecting the increased heat loss in the wellbore due to the lower velocities, but this drop will be minor compared to the rapid drop in wellhead pressure which occurs when the obstruction becomes large enough to choke the flow downhole. (See Figure 1.) Figure 2 shows the very rapid drop in flow rate and wellhead pressure associated with scaling in the borehole. This data was collected at the end of a three-month flow test where scale deposition was very slow and probably spread over a long section of the borehole during early parts of the test, due to a large amount of dissolved CO_2.

CASE 3: SCALE IN THE RESERVOIR - CONSTANT RATE TEST

If flow rate is held constant while scale accumulates either in the reservoir or at the perforations of a liner, downhole pressure will give the appearance of a reservoir with either a no-flow or low-permeability boundary. (See Figure 3.) As reservoir scale continues over a long time period, it will become impossible to maintain a constant rate due to very large pressure losses and reduced permeability, especially near the wellbore. Reservoir scale is much more likely when a single-phase reservoir becomes two-phase, due to pressure drops caused by production. The largest flow volume through the smallest area occurs near the wellbore with the result that scale will build-up most rapidly in this zone. For this reason, pressure build-up in a well where scale has occured in the reservoir should show a large skin effect where skin effect during drawdown would be much smaller. (See Figure 4.) Pressure build-up data also should not show any boundary effects.

CONCLUSIONS

Observations of test results show that build-up of scale in the wellbore is difficult to detect during early time. Increased frictional pressure losses due to the thin layer of scale deposited in the two-phase region make up a small percentage of the total pressure losses contributing to the wellhead pressure and may result in a decrease in wellhead pressure of less than 2 psi in 5000 feet of wellbore.

The build-up of scale in the reservoir will give erroneous results if reservoir properties are calculated from drawdown curves. Build-up curves will show extremely large skin effects. Since pressure drop across the obstruction may lower the flash point in the wellbore, downhole pressure measurements may be slightly affected by scaling during a constant rate test. Drawdown and build-up curves should be compared to see if this effect is present.

When scale begins to build in one section of the borehole, however, it is very likely the flashing will occur in the narrowest part of this obstruction, due to the rapid pressure drop (Simoneau, 1975). The speed of sound in a two-phase liquid is given by the equation:

$$\frac{1}{c^2} = -\rho^2 \left(\frac{d\overline{V}_\ell}{dP} (1-x) + \frac{d\overline{V}_g}{dP} x + \frac{dx}{dP} \overline{V}_{g-\ell} \right)$$

where c is the speed of sound, ρ is the density of the mixture, x the quality, $\overline{V}_\ell$ is the specific gravity of the liquid and $\overline{V}_g$ is the specific gravity of the gas. Combining this with the Clausius - Clapeyon equation and looking at the limit for zero quality we have:

$$\lim_{x \to o} \frac{1}{c^2} = -\rho^2 \left(\frac{d\overline{V}_\ell}{dP} - \frac{\overline{V}^2{}_{g-\ell}\, C_\ell\, T}{L^2} \right)$$

where C_ℓ is the specific heat of the liquid, T is the temperature, and L^2 is the heat of vaporization (Rohatgi, 1975). This gives a velocity for the speed of sound right at the point where nucleation of vapor begins in water at atmospheric pressure of 6 ft/sec, which is a great deal less than 4794 ft/sec, the velocity of sound in liquid water. At a mass flux of 300,000 lb/hr, choking would occur in an opening 14 inches in diameter. For water at saturation pressure for 400^{o} F, this discontinuity is less and an opening of 2 inches will choke the flow. Since changes in upstream pressure in a choked flow will not cause changes in the flow rate, we can determine the point when choking occurs by opening a throttle valve or test choke if we are throttling the well. We can then determine the speed of sound for the inception of boiling for the reservoir temperature and calculate the size of the opening needed to cause choking using the equation:

$$A = \frac{Q}{\rho c}$$

where A is the cross-sectional area at the obstruction, Q is the mass flux, ρ is the density of the liquid and c is the speed of sound at the flash point.

REFERENCES

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2. Simoneau, R. J.: "Pressure Distribution in a Converging-Diverging Nozzle During Two-Phase Choked Flow of Subcooled Nitrogen," in Non-Equilibrium Two-Phase Flows, American Society of Mechanical Engineers, November, 1975.

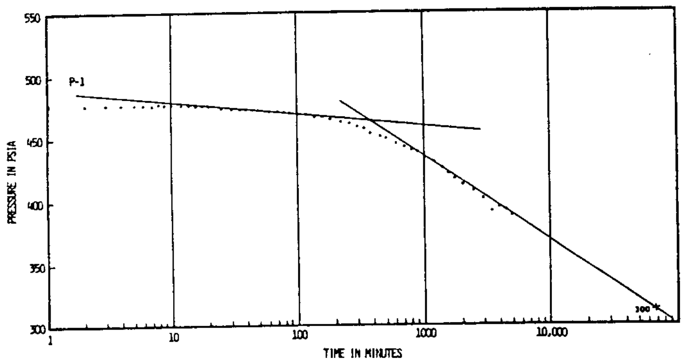

Figure 1. Constant Rate Test - Pressure Drawdown (7/12 - 7/19/82).

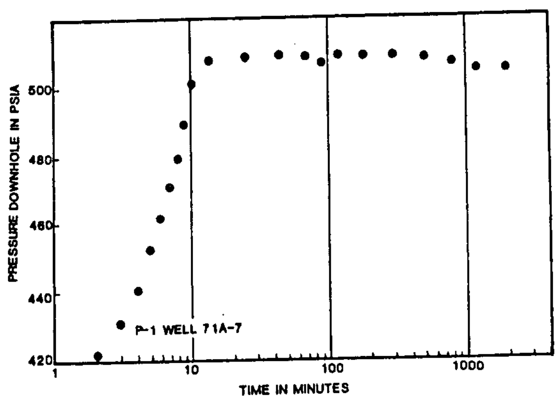

Figure 2. Constant Rate Test - Pressure Build-up (7/19 - 7/23/82).

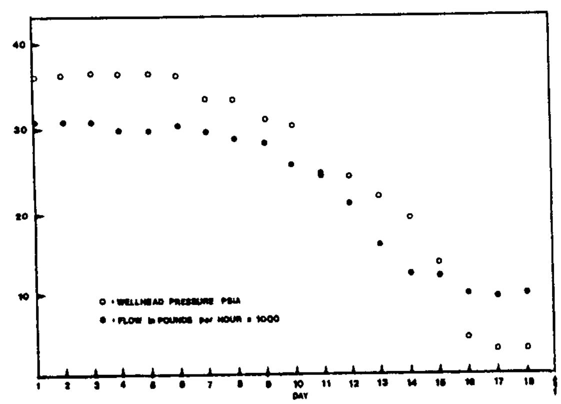

Figure 4. Falling Rate Test - Wellhead Pressure & Flowrate.

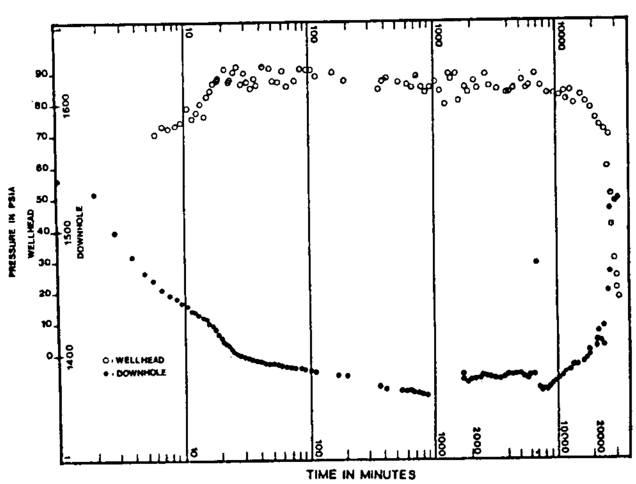

Figure 3. Falling Rate Test - Wellhead & Downhole Pressure.