Understanding Wellbore Cooling

Halliburton has been conducting pressure transient tests from the surface for years. Over this time we have developed many techniques to overcome the challenges that are uniquely related to surface testing. One of the most significant challenges to surface test is the matter of wellbore cooling. This article will discuss the nature of wellbore cooling as well as the work Halliburton had done to correct for it.

Before discussing the effect that wellbore cooling has on surface testing it is useful to understand the basis behind calculating bottomhole pressures from surface data. The basic equation governing the conversion of wellhead pressure (WHP) to bottomhole pressure (BHP) is the following (ignoring kinetic energy and other negligible effects):

\[ BHP = WHP + \rho gh + f. \]  

In the above equation \( \rho gh \) is the hydrostatic head component of the wellbore fluid and \( f \) is the pressure drop due to friction. Since pressure transient analysis is the science of pressure change, looking at the change of each of these components results in this modification of the governing equation:

\[ \Delta BHP = \Delta WHP + \Delta (\rho gh) + \Delta f. \]  

Wellbore cooling begins once a producing well is shut in. While a well is flowing, the produced fluids are bringing heat from the reservoir to the surface raising the wellhead temperature (WHT). The amount of increase is due to a number of factors such as gas rate, liquid gas ratio, bottomhole temperature and the specific heat of the wellbore fluids. In some environments, this can cause WHT's to approach 300°F. Upon shut-in, this heat source is lost, and the wellbore will begin to cool. As the wellbore cools, the wellbore fluid density and corresponding hydrostatic head both increase. Rearranging the above equation allows us to understand the effect this change in density has on surface pressures:

\[ \Delta WHP = \Delta BHP - \Delta (\rho gh) - \Delta f. \]  

For a shut-in well frictional losses are zero and thus \( \Delta f \) is zero. For moderate to high permeability wells \( \Delta BHP \) will be fairly small, as the pressure in the reservoir tends to stabilize fairly quickly. For these types of wells, the change in hydrostatic head (\( \Delta \rho gh \)) will be larger than \( \Delta BHP \), resulting in a negative \( \Delta WHP \). This means the surface pressures will decline over the course of the build-up.

This is one of the more interesting phenomena that one may encounter when conducting a build-up test at the wellhead. An engineer new to surface testing may mistakenly write this off as a bad test that cannot be analyzed. Experience has shown us that this is an effect of wellbore cooling during a build-up.

We have developed a proprietary thermal decay model that accounts for wellbore cooling. This empirical model was developed through testing with surface and downhole gauges simultaneously. It accounts for cooling wellbore temperatures over the course of a build-up and enables us to properly account for increasing hydrostatic head over the course of a shut-in. It is a vital component of our model and enables Halliburton to interpret datasets that would otherwise be unanalyzable or mis-analyzed. Figure 1 below illustrates the effect that correcting for wellbore cooling can have:
Two pressure curves are displayed on this graph. The blue line represents the converted BHP’s when we do not account for the increased hydrostatic head due to wellbore cooling. The red line represents the converted BHP’s when Halliburton’s thermal decay model is employed. For this test, correcting for wellbore cooling increased the final calculated BHP by over 100 psi. It is important to understand that regardless of the permeability of the well, wellbore cooling occurs during a build-up. Even if surface pressures continuously increase throughout the shut-in, failing to account for wellbore cooling will result in erroneous calculations for skin, permeability and P*.

Wellbore cooling is a complex phenomenon and a challenge that must be overcome when testing from the surface. To discuss this further or for any testing needs you may have, please call or email Halliburton at 281-444-5398 or spidr@halliburton.com

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