**Introduction**

Well response testing has evolved to a frequently applied technique when evaluating the hydraulic conductivity of the subsurface are required. Traditionally, slug tests are conducted by using just one initial displacement \( H_0 \), Classical linear flow theory is applied for the analysis of these tests as they do not allow for a dependency of overdrawn or normalized head data on the initial displacement \( H_0 \). Additionally, overdrawn or normalized head data are usually obtained when a non-linear reservoir test curve is utilized at time for varying initial displacements \( H_0 \). We consider classical linear flow theory to often be inadequate at describing such test data.

**Model Development**

In order to gain more insight into the process governing our data, we developed a nonlinear near-well response test model for fully penetrating hydraulic discontinuities \( \text{Zimmer, 2008, 2009)} \). This model accounts for three major nonlinear flow processes: a) a water column height depending on the actual head displacement \( H(t) \), b) nonlinear wellbore-head loss due to turbulent flow and inertial effects at radius changes along the flow path inside the well casing, and c) non-linear flow skin effects to accommodate near-wellbore non-linear flow inside the test formation:

\[
\frac{dH}{dt} = \frac{1}{\phi} \left[ \frac{1}{k} \int_0^H (H_{\text{sw}} - H(t)) \, dt - q \right] - \frac{k_p}{\phi} \left[ \frac{1}{k} \int_0^H (H_{\text{sw}} - H(t)) \, dt - q \right] \frac{1}{\phi} \log \left( \frac{r_o}{r_i} \right) \]  

Model eq. (1) relates to the schematic of Fig. 1. The initial constant head.

\[
\phi = \frac{1}{k} \int_0^H (H_{\text{sw}} - H(t)) \, dt - q \]  

**Example 1: Coarse Sand Aquifer**

The first application of the above model (eq. 1) demonstrates the applicability of Boral and Bruce-Carr type pressure gradient inside the well casing and assumes that far-field flow away from the well is cylindrical groundwater and Darcian. This model will be applied subsequently to test the problems between testing-controlled and formation-controlled non-linear flow processes. The key to arrive at such a differentiation is to conduct several well responses initiated by different initial head values \( H_0 \) and to describe wellbore-related non-linear head losses by known head loss formulas from physical and hydraulic models. Existing procedure essentially is the slug test analogue to classical well performance testing by step-pumping example.

**Example 2: Fractured Limestone Aquifer**

The previous test example showed that non-linear wellbore-flowing non-flow processes are accounted for by head loss formulas tabulated in steady-state pipe hydrodynamics. These formulas are used to discriminate between nonlinear flow characteristics originating inside the wellbore and inside the test formation, respectively. The current test example refers to a set of non well test responses conducted on October 25, 2006 at well Mühlbruchfeuerla 82, which was located in the Devonian limestone formation close to the small town of Hambach at the eastern part of the Erzgebirge region in Germany. The test limestone formation is known to be fractured according to hydrogeological investigations at nearby waterworks Uhle. The test sequence and the construction plan of well Mühlbruchfeuerla 82 are shown in Fig. 4. The test limestone formation is oscillated by fracturing marble, which in turn reduces the test response curves belonging to different initial displacements \( H_0 \) and differing test settings initiated by differing initial displacements \( H_0 \).

Conclusions

This work showed that an identification of near-wellbore flow processes in generally permeable aquifers is possible by conducting several well responses with significantly different initial displacements \( H_0 \) in a well along with representing non-linear wellbore non-flow processes. Therefore, a head loss formula from steady-state pipe hydrodynamics is applied to describe the wellbore-related non-linear flow response testing along with an application of non-linear mathematical models to analyze acquired head loss formulas. The test results demonstrate that the wellbore loss flow response testing should be supplemented by production logging or an advanced borehole imaging methods (e.g. formation micro- or ultrasonic borehole logging) whenever possible to maximize structural and hydraulic information on investigated fractured systems.

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References