Simulation of Groundwater Flow Patterns Around a Vertical Circulation Well

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Abstract

Vertical circulation well (VCW) is a well system consisting dual-screened sections that allow for injection and extraction from a common borehole. Since the last two decades, VCWs have been widely used for in-situ remediation [4, 10], and for aquifer characterization [2, 11]. Recently, VCW has also been introduced for groundwater lowering, which is known as DSI-well [3, 5]. Groundwater is extracted from one of the screened section and re-injected into the other section. A packer is installed to isolate the screen sections, and to maintain the upward or downward flow direction. In this article, we demonstrate the downward flow system, where drawdown is achieved at the upper part of the aquifer. The concept of VCW and/or DSI-well is described in figure 1.

The various applications of VCWs led to the intensive research to evaluate the groundwater flow patterns around the well. For instance, analytical solutions were derived considering simple geometry with idealized cases [2]. Moreover, relatively complex cases, for example, tracing the free-surface movement, were simulated in previous studies using COMSOL Multiphysics® [5, 7]. Nevertheless, the precise flownets of the recirculation field has not been derived yet. Therefore, this study aims to simulate the exact flownets and to provide a comprehensive simulation of the groundwater flow patterns around VCWs.

The model mainly consists of three components: 1) groundwater flow simulation, 2) free-surface tracing and 3) streamline simulation. Groundwater flow equation derived from Darcy's Law and fluid mass conservation was solved in the model [1]. When unconfined aquifer is considered, the movement of the groundwater table (free-surface) is traced by utilizing the arbitrary Lagrangian-Eulerian (ALE) method [8, 9]. Moreover, the intensive circulation field is described by additionally coupled the stream function [1, 6]. Hence, the precise flownets with equal fluxes can be determined.

The simulation result demonstrates the fundamental flow configuration induced by a VCW or

DSI-well at steady-stat. A 2D vertical cross section is depicted in figure 2, where the circulation flow is generated at inner boundary. When unconfined aquifer is considered, the position of the free-surface is presented by the deformed mesh, while its initial position is given by the upper solid line. Lower potential of hydraulic head is calculated near the extraction screen (blue color), while higher potential of hydraulic head is induced near the injection screen (red color). Hydraulic head equipotential lines are shown by black contours. The solid curves (red color) are the position of streamlines representing the 20%, 40%, 60% and 80% groundwater flow respectively around the well. In addition, the velocity field is laid out via the arrow plot.

To conclude, the presented model is able to provide comprehensive simulation of groundwater flow patterns around a vertical circulation well. By utilizing ALE method, the movement of the free-surface is traced. Moreover, the model determines the flownet accurately, which may enhance the application of circulation wells in field.

Reference

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Figures used in the abstract

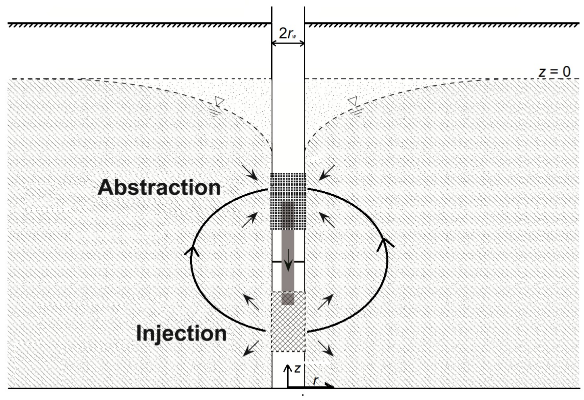

Figure 1: Schematic diagram of groundwater flow around a VCW and/or DSI-well.

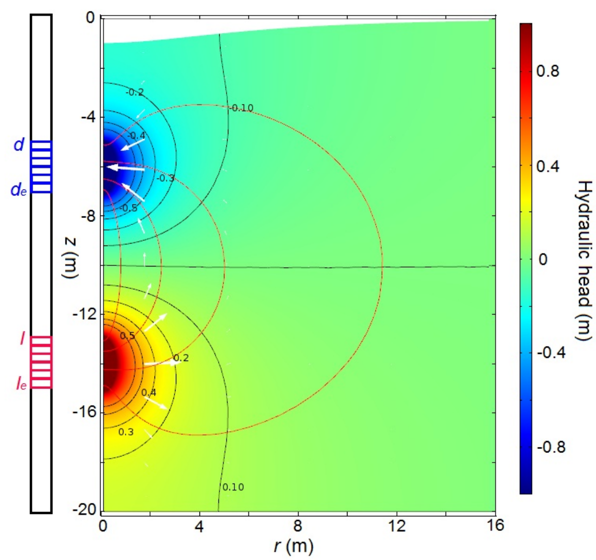

Figure 2: 2D vertical cross-section simulation output of flow filed induced by a VCW or DSI-well. The hydraulic head (color plot), position of groundwater table (deformed mesh line), equipotential contours (black solid lines with label), velocity field (arrow plot), 20%, 40%, 60%, 80% streamlines (red solid lines); are presented.