Hydrogeology Journal (2018) 26:2531–2541
https://doi.org/10.1007/s10040-018-1857-4

TECHNICAL NOTE

Well-bore clogging of a pumping well in hydraulic interference with an ambient groundwater flow: the Strack-Kostitsina refraction problem in an annular composite redux

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Received: 9 December 2017 / Accepted: 15 August 2018 / Published online: 14 September 2018

Abstract
Explicit expressions for the vector fields of specific discharge and scalar fields of stream functions and piezometric heads in a Darcian steady-state essentially two-dimensional (2-D) flow through a three-component composite representing a vertical or horizontal well with a gravel pack and annular skin are obtained and analysed. The refraction conditions along two concentric circles, which represent interfaces between three porous media of contrasting hydraulic conductivities, are exactly satisfied. Flow nets, isotachs, the locus of the stagnation point bounding the capture zone of the well, and functionals quantifying area-averaged hydraulic characteristics are found. The flow topology and drawdowns near the well illustrate that at small pumping rates a common concept of a purely radial 1-D flow can be superficially plausible but misleading.

Keywords Analytical solutions · Groundwater hydraulics · Skin effect · Formation damage · Complex variables

Introduction

Mechanical clogging (hereafter abbreviated as MC), also called a "positive skin" on well bores of groundwater and oil abstracting wells, is a daunting problem attributed to retention of the drilling mud by the near-wellbore rock and incomplete well development, as well as gradual deposition of fine particles in the vicinity of an initially "clean" zone of contact between the gravel pack and rock. These particles get suspended in the fluids transported towards the well as long as high hydraulic (pressure) gradients are maintained by an intensive pumping from the aquifer/formation. Theoretical models of pore-level kinetics of MC formation, core data from the field, laboratory experiments, taxonomy and methods of de-clogging are presented by De Zwart (2007), Houben et al. (2016), Houben and Treskatis (2007), Ivanova et al. (2018), van Beek et al. (2009, 2017), among others. There is, however, a gap in the studies of flow to wells with MC, as well as studies on situations that emerge when stimulation (e.g. acid injection) makes a highly permeable zone near the wellbore. Specifically, on a Darcian (continuum) scale, most steady state or transient flows in the vicinity of skinned wells follow the protocol of Everdingen-Hurst-Hawkins-Moench-Hsieh, i.e. assume a purely radial flow towards a pumped well. To the best of the authors' knowledge, only Strack (2017) and Kostitsina (1966) addressed the problem of an essentially non-one-dimensional (1-D) flow by considering mathematically rigorous conditions of refraction on circular interfaces between zones of contrasting hydraulic conductivity. This article extends the Strack-Kostitsina analytical solutions. Information on three additional relevant papers (in Russian) is given in the electronic supplementary material (ESM).

The vicinity of a vertical or horizontal groundwater or oil well is commonly schematized as a perforated tube (screen), a surrounding gravel pack within a drilled borehole, a thin

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10040-018-1857-4) contains supplementary material, which is available to authorized users.

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