

Injection-Abstraction Well Pair in a Porous Formation with an Eccentric Skin Effect of a Gravel Pack and Damaged Zone

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Abstract— Steady, 2-D, saturated, one-phase flow of a fluid (water, oil) from an injection to production well is analyzed by the methods of complex variables. The aquifer (formation) is homogenous and of a constant thickness but the vicinity of the well consists of two circular zones of much higher and lower permeability than that of the aquifer. Refraction of streamlines takes place on the two circular interfaces. The conjugation conditions (pressure and normal flux continuity) are exactly met and three fields of Darcian velocity in the three zones are exactly written in terms of well-converging series. The flow net and isotachs are reconstructed by computer algebra routines.

Index Terms— Pumping-injection well, skin-factor, heterogeneous permeability, topology of refraction,

I. INTRODUCTION

In reservoir engineering/groundwater hydrology formation/aquifer rock adjacent to a borehole is often damaged by mud liquids during well drilling or stimulated by various mechanical or chemical agents during well completion/development/rehabilitation (fracturing, acid injection, jetting, etc. - aimed at increasing the permeability of the vicinity of the well [1],[2]). As result, an originally homogeneous or almost homogeneous bulk porous medium has a sink/source (well) surrounded by a sheath of a porous (or fractured) material, whose permeability is significantly (sometimes, orders of magnitude) higher or lower than that in the undamaged (pristine) pre-stimulation conditions. Standard engineering formulae used in assessing well productivity in terms of injected-abstracted volumes and pressure/velocity fields either consider no well sheath or assume a simple "skin-factor" for a sheath placed concentrically with the sink. Obnosov *et al.* [3] obtained explicit analytical solutions which take into account an eccentric heterogeneity close to the well and illustrated that the flow refracted in such zones becomes intricately complicated. Obnosov [4] obtained an explicit solution for a Darcian flow induced by arbitrary singularities (multipoles) and refraction by an eccentric annulus, which models the well sheath.

In this paper we consider a production well placed eccentrically with its gravel pack, which is also eccentrically

located with respect to a formation damage, both embedded into a rock matrix. The corresponding zones are denoted by S_3 , S_2 and S_1 . Fig.1 shows a cross-section of the formation perpendicular to the well axis.

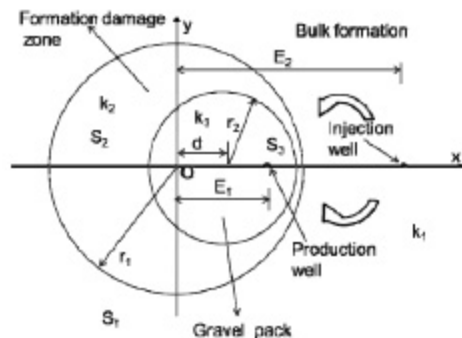


Fig.1 Formation cross-section perpendicular to the well axis

We assume that the well is perfect, i.e. a barefoot one is completely filled with a production fluid, there is no entrance resistance into the borehole due to smallness of perforations (if the well has casing), there is no pressure drop along the well axis and the inflow rate (per unit length) into the well, Q , is a constant value. The damaged zones and gravel pack are assumed to be perfectly circular in cross-sections of Fig.1a and the radii of the circles are r_1 and r_2 , respectively, $r_1 > r_2$. The origin O of Cartesian coordinates (x, y) coincides with the centre of the damage circle (Fig.1). Fluid flow is assumed to be one-phase, 2-D, Darcian and - owing to the full saturation of all three zones in Fig.1 capillarity is ignored. Phase permeabilities (and hydraulic conductivities k_3 , k_2 , and k_1) are constant within each zone but jump across the circular interfaces in Fig.1. Fluid injection takes place through another well placed in zone S_1 . From mass conservation the injection rate of this well is $-Q$, i.e. of the same magnitude but opposite sign compared to the abstraction well. Far away from the dipole in Fig.1 the fluid is quiescent.

The coordinates of the wells in Fig.1 are (x_0, y_0) and (x_1, y_1) . Schematically, the flow direction is indicated by arrows in Fig.1. The objective of this paper is to analyze the refraction pattern which depends on r_1 , r_2 , eccentricity e_1 , (x_0, y_0) and (x_1, y_1) , Q , and hydraulic conductivities.

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