3D VERTICAL CIRCULATION FLOWS AROUND WELLS WITH TWO SCREEN SECTIONS FOR AQUIFER REMEDIATION: NUMERICAL RESULTS

B. Herrling, J. Stamm
Institute of Hydromechanics, University of Karlsruhe
D-7500 Karlsruhe, Germany

Abstract

Three-dimensional vertical circulation flows around wells with two screen sections in one aquifer are discussed in case that a vertical discharge through the well casing is initiated without any extraction or infiltration. Furthermore, these flow systems are used in combination with a partial discharge withdrawal or infiltration taken from or added to the total discharge through the well casing to avoid head changes at the top. The paper first presents results of the resulting flow system to characterize the circulation. Further, a lot of diagrams are presented which can be used to dimension those special wells with vertical circulation flows.

Introduction

Groundwater Circulation Wells (German abbr.: GZB) and Vacuum Vaporizer Wells (German abbr.: UVB) have two screen sections in one aquifer, one at the aquifer bottom and one at the groundwater surface or below an aquitard [1,2]. The groundwater within the well moves vertically and thus produces a groundwater circulation in the surrounding aquifer. This circulation flow is overlapped with the natural groundwater flow.

These flow systems are used for in situ or on-site aquifer remediation. The contaminated groundwater is cleaned by different measures, while it passes the well casing, or within the well nutrients and/or electron acceptors are added for bioreclamation using the aquifer as a bioreactor [2,3]. Further, this flow system can be employed to extract or infiltrate groundwater without any change of heads at the well top [3,4]. All these technologies have been patented by IEG mbH, D-7410 Reutlingen, Germany.

The vertical circulation flow around the UVB and GZB has been a matter of continuous numerical investigations [4]. Hitherto this has been realized only for confined aquifer conditions, which permits the superposition of the flow fields of different wells and the natural groundwater flow; the local below atmospheric pressure field (in case of a UVB) is neglected. Further, density effects are ignored; only steady-state conditions are taken into account, and, for esimating the capture zone, only convective transport is considered.

Resulting flow system of a UVB or GZB

The general character of the vertical circulation flow is demonstrated in Figure 1: In a vertical longitudinal section parallel to the natural groundwater flow, streamlines mark the flow around one (Fig. 1a) and two (Fig. 1b) upward pumping GZB or UVB, their separation being made equal to the distance between stagnation point and well axis. The strong verical circulation flow especially between the two wells (Fig. 1b), which is extreme beneficial in a highly polluted area near the contamination sources, is evident.

Fig. 2 presents a view on the numerical calculated separating stream surfaces of nine water bodies in

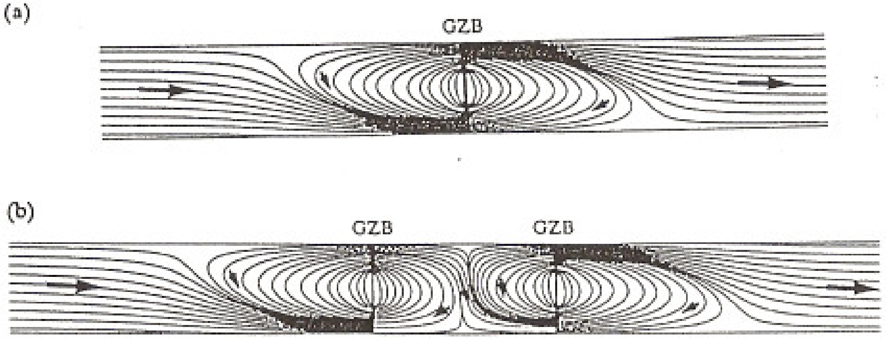

Fig. 1 Streamlines around (a) one and (b) two UVB or GZB demonstrated in a vertical longitudinal section parallel to the natural groundwater flow

connection with the flow around three UVB or GZB. They are positioned at a maximum distance normal to the natural groundwater flow so that no water can pass between the wells without having been treated. With the contaminated groundwater flowing from the left the following salient features can be clearly seen: the separating stream surfaces of the contaminated water captured by the three

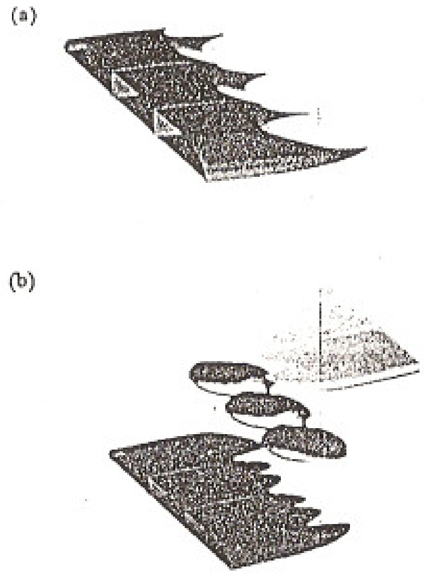

Fig. 2 Separating stream surfaces of the different water bodies in the outside flow of a GZB: captured, circulating, and flowing downstream water in (a) a real situation and (b) water bodies separated for clarification

UVB or GZB (left), the surface of the water bodies having been treated and circulating around the wells (center), and of the treated water flowing downstream (right). The calculation was performed using the parameters: $Q/(H^2v) = 16.1$, $a/H = 0.25$, and $K_H/K_V = 10$. Q denotes the vertical discharge through one well, H the aquifer thickness, v the natural Darcy velocity at the site, a the length of the upper or lower screen section, and K_H and K_V the horizontal and vertical hydraulic conductivities.

Numerical results in case of presence of natural groundwater flow

At most remediation sites, a natural groundwater flow exists. Figure 3 shows numerical results represented in dimensionless form for the dimensioning of UVB and GZB installations under these conditions. In figure 3a, the horizontal distance (S) of the stagnation point from the well axis is described. The ratio S/H is dependent on the parameters $Q/(H^2v)$, K_H/K_V, and a/H. The location of the stagnation point is highly sensitive to the anisotropy of the aquifer. The length of the screen section is of small importance within usual proportions. The knowledge of the distance (S) from the stagnation point can be used to determine the positioning of the measuring equipment.

The results of figure 3b-d have been calculated for an upstream distance of 5H from the well and for a constant ratio of $a/H = 0.25$. The results are discussed for wells that pump upward. The widths B_T and B_B of the upstream zone, measured at the aquifer top and bottom, are shown in figure 3b. The ratios B_T/H and B_B/H are again dependent on the ratios $Q/(H^2v)$, K_H/K_V, and a/H. For small values of $Q/(H^2v)$, the upper part of the capture zone does not reach the top of the aquifer. This implies that for remediating a plume, a minimum well discharge (Q) is required. Again, the results are quite sensitive to the degree of the anisotropy.

When remediating a wide contamination plume, several wells are used in a line normal to the direction of the natural groundwater flow. The length (D) denotes the maximum well distance at which the contaminated groundwater cannot pass between the wells without being cleaned or treated. The ratio D/H is dependent on the same parameters as before. When a plume of width W is to be cleaned, the number (n) of well installations can be estimated by $n = (W-B_T)/D+1$.

When a plume is remediated, the contaminated water of quantity Q_0, flowing into the capture zone of a single well from upstream, is diluted with water that has already flowed through the well and circulates around it. Thus, the contaminant concentration of the water within the well casing will be lower than in the upstream plume; near a contamination source the situation is reversed. Figure 3d illustrates the portion Q_0 of the total well discharge Q. The ratio Q_0/Q is again dependent on the same parameters as the widths of the upstream capture zone. Figure 3d can be used to estimate the expected concentration value of the water within the well casing for the dimensioning of a well installation. It may help to evaluate the progress of remediation at a site when concentration data of the upstream plume and the water within the well are determined.

The sphere of influence of the circulation around a UVB and GZB at sites with natural groundwater flow is of special interest. In the direction of natural groundwater flow, this sphere has a maximum expansion of S (see figure 3a) to the upstream and downstream sides. Normal to this direction, the maximum radius of the sphere of circulation is approximated by $(B_B + B_T)/4$ (figure 3b), and in the case of several wells in one line by D/2 (figure 3c).

Figure 3 can be used for the dimensioning of one UVB and GZB or a UVB and GZB field when the parameters K_H/K_V and $Q/(H^2v)$ can be estimated, where Q depends on the well size and on the additional pump. For an irregular well field, a layered aquifer, or special critical cases, additional numerical calculations can be performed.

Numerical results in case of groundwater extraction or infiltration using a GZB

Presently, numerical results are only available for the case of absence of natural groundwater flow and

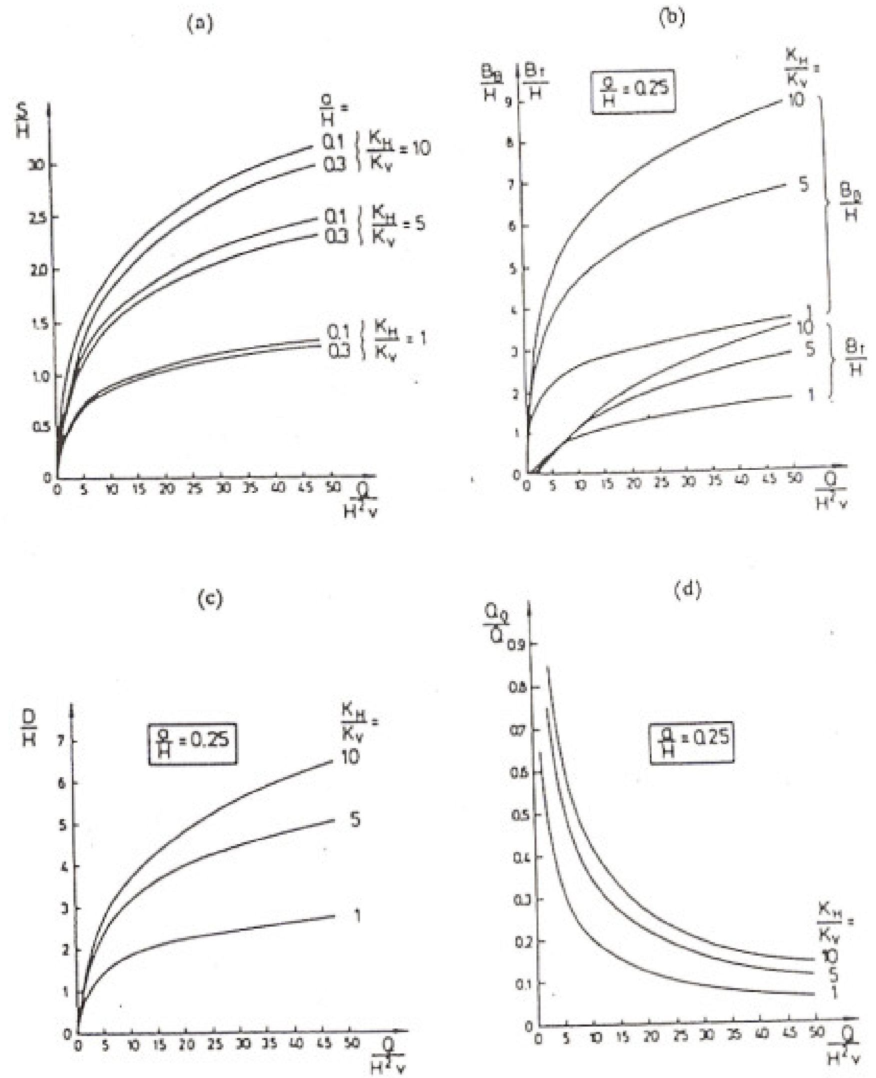

Fig.3 (a) Distances (S) of the stagnation point from the well axis, (b) widths(B_T) and (B_B) of the upstream capture zone at the aquifer top and bottom, (c) maximum well distance (D) at which the contamintated groundwater cannot pass between the wells without being treated, (d) upstream discharge (Q_0) in the capture zone, which is diluted with the circulating water to the total well discharge (Q)

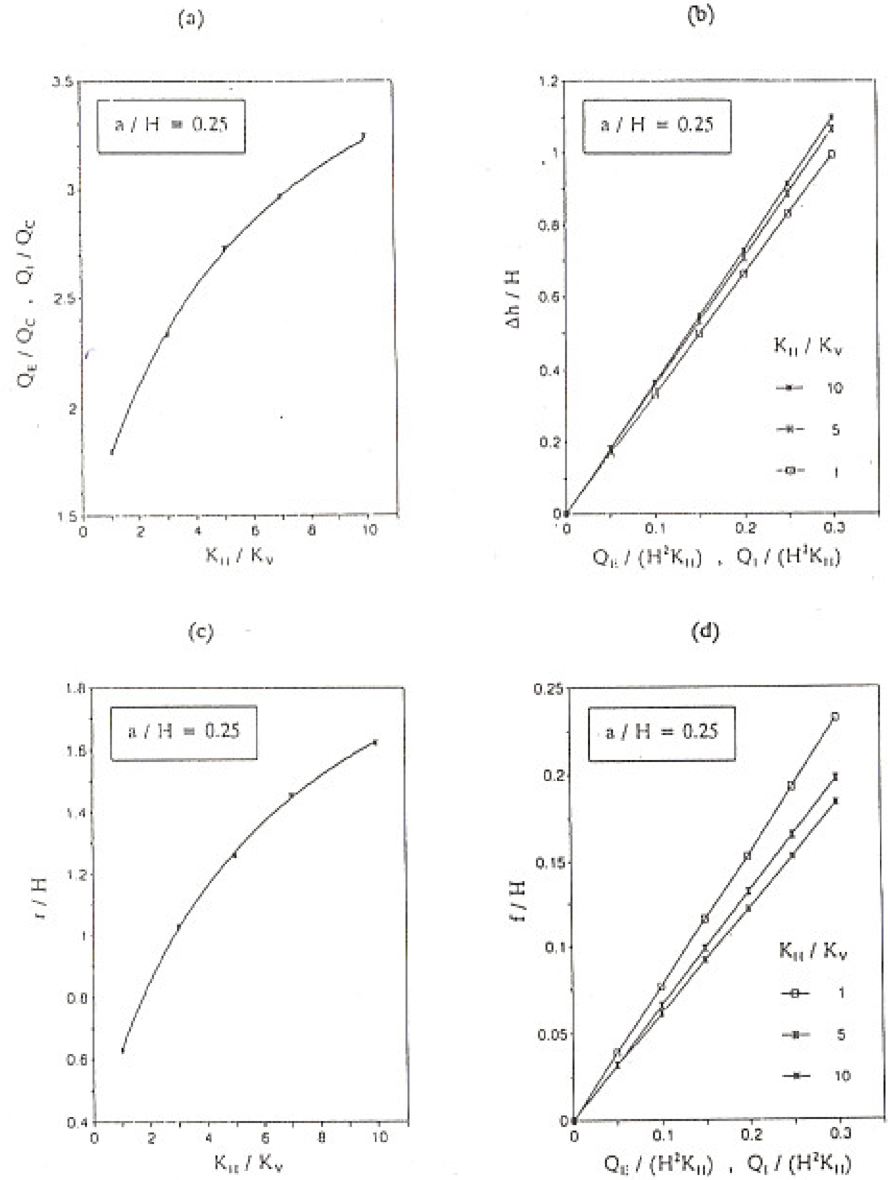

Fig. 4 (a) Ratio Q_E/Q_C and Q_I/Q_C for no head change at the well top, (b) head changes Δh at the well bottom, (c) distance r from the well axis with maximum head deviation, and (d) maximum head deviation f

for confined aquifer conditions. When a GZB is used to split the vertical well discharge (Q), pumped from the lower screen section, into a quantity (Q_E) which is extracted and an amount (Q_C) which is infiltrated in the upper screen section and which generates the circulation flow around the well, the possibility exists to avoid any change of heads at the well top for a special ratio of Q_E/Q_C [3,4]. This ratio is only dependent on K_H/K_V and a/H. Figure 4a demonstrates for a/H = 0.25, Q_E can be about two to three times of Q_C depending on the aquifer anisotropy. For this special ratio of Q_E/Q_C, the decrease of the head at the well bottom (no change of the heads at the well top) is $-\Delta h$ (figure 4b). In a dimensionless description, $\Delta h/H$ is dependent on the parameters $Q_E/(H^2K_H)$, K_H/K_V, and a/H (figure 4b: a/H = 0.25). Using this diagram, an important check of whether the danger of cavitation will be existing below the packer can be carried out.

In case of infiltration of a quantity (Q_I) in a GZB, the ratio Q_I/Q_C can be taken from the diagram of figure 4a as well, when no change of heads are demanded at the well top. In this case, Q leaves the GZB through the lower screen and Q_C enters the well through the upper screen [3,4]. The increase of head (Δh) at the well bottom can be estimated from figure 4b.

In some distance (r) from the well axis, a maximum head deviation (f) from the resting water level will result at the aquifer top. The dimensionless parameter r/H is dependent on K_H/K_V and a/H, and f/H (negative for groundwater extraction and positive for infiltration) depends on $Q_E/(H^2K_H)$, K_H/K_V and a/H. Figures 4c and 4d represent results for a/H = 0.25.

Conclusion

The broad applicability of vertical circulation flow systems around a UVB or GZB has been shortly demonstrated for various in situ and on-site remediation techniques. On the basis of confined aquifer conditions the resulting 3D flow systems for one and several UVB and GZB units have been characterized (sphere of influence, capture zone, head changes, etc.) by dimensionless diagrams as a result of extended numerical computations. By that, remediation measures can be dimensioned. One of the surprising results is that well extraction or infiltration is possible without head changes at the well top which will have considerable significance in practice. The capture zone of a circulating pumping well in a natural groundwater flow field is going to be investigated.

Acknowledgement

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