THREE-DIMENSIONAL STUDY OF STREAMFLOW DEVELOPING AROUND RADIAL WELLS

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Abstract

Based on the completed three dimensional electric analogous studies the following main points can be established:

1. In case of a radial well sited in an extensive horizontal layer:

a) the capacity of well is proportional to the 0.87th power of the thickness of the layer,

b) the increase of the number of horizontal pipes with the same total length causes just a slight decrease in discharge, therefore, when determining the number of horizontal pipes, they are not the hydraulic aspects which are decisive,

c) limiting the perforation just for the outer half length of the horizontal pipe causes about a 5% reduction in discharge only.

2. In case of a radial well sited near a river-bed, the horizontal pipe in the direction opposite to the river-bed can be omitted without any considerable decrease in discharge.

3. The horizontal pipe reaching under the riverbed considerably increases the discharge, but can result in a rapid colmation.

4. Colmation extends the influence of the well on a longer section of the river-bed, that is why its effect to decrease the discharge develops relatively slowly.

5. Enlightening the development of physical, chemical and biological colmation is by all means necessary to forecast and delay the "ageing" of wells.

Introduction

Water supply from radial wells is one of the widespread forms in settlements because of its high efficiency of water acquisition and water intake. Its application is widespread in gravelly alluviums, mainly along water courses.

The aim of this study is to show the relationships between certain hydraulic characteristics of water intake with radial wells based on electric analogous investigations considering radial well dimensions customary in practice.

1. Subject of the study

1.1. The examination of the potential field, the capacity and its distribution around radial wells with a total length of 300 m horizontal pipes sited in a confined aquifer which is considered horizontally infinite, in the case if the number of horizontal pipes is between 2 and 10, and the pipes are uniformly arranged around the shaft, the total length of perforation varies and the friction loss in the pipes is neglected. The diameter of the shaft is 2.2 m, that of the pipes is 0.219 m, the thickness of the aquifer is 5 and 10 m, the coefficient of permeability $k = 10^{-2}$ m/s, the distance between the axis of the pipe and the lower horizon of the aquifer is 1.00 and 1.70 m.

1.2. The examination of the potential field, the capacity with its distribution and that of the specific discharge of the bank infiltration of a radial well with 4 horizontal pipes, each 1.70 m above the lower horizon of the aquifer near an idealized river-bed if:

a) the pipes do not reach under the river-bed, and

b) the pipes reach under the river-bed.

In both cases the well has the dimensions given above.

The river-bed reaches down into the aquifer with a depth of 5 m. We remark that the effect of the filter layer around the pipe with different coefficient "k" is replaced by a virtual pipe diameter of 0.25 m and a homogeneous coefficient "k".

2. Results of the examinations

2.1. Examinations in horizontally infinite aquifer

During the examination we supposed that the potential along a circle with a radius of $R = 197$ m is already constant. Later we give reasons why it was possible. The effect of the vertical arrangement was studied in case of 4 horizontal pipes, each perforated along their total length.

Based on measurements, we established that the vertical situation of the horizontal pipe (1.00 or 1.70 m above the lower horizon of the aquifer) does not give a reasonable difference in discharge, though theoretically the higher one is more advantageous. Further studies were done with pipes at the height of 1.70 m.

The discharges of radial wells were compared in an aquifer of 5 and 10 m, in both cases with 2, 4, 6, 8 and 10 totally perforated horizontal pipes. It is established that between these limits the capacity "Q" is nearly proportional to the thickness of the layer "b" and dependence on the number of pipes cannot be shown:

$$\frac{Q_b}{Q_{b_0}} = \left(\frac{b}{b_0}\right)^{0.87}$$

Thus, the discharge gained from a 5 m thick layer is 55% of the discharge from a 10 m thick layer. But in thinner layer the infiltration over unit length decreases slower at the outer end of the pipe than at the shaft. Comparing the average infiltration over unit length at the outer 20% of the pipe in the case of the 5 and the 10 m thick layers, in the thinner layer the infiltration is 65% of that of the thicker layer. On the other hand, at the 50% length of the pipe nearer the shaft the discharge over unit length in the thinner layer decreases to 46%. These results can be logically understood on the basis that the friction loss of the seeping water is concentrated around the pipe mainly at the outer end of the pipe.

The examination of the radial wells with 2, 4, 6, 8 and 10 totally perforated pipes, of which Fig. 1 shows an example, supported the assumption of the $R = 197$ m cylindrical field instead of the infinite space. The biggest length of a pipe was in case of 2 pipes, 150 m, that is 76% of the mentioned radius. If the pipe on Fig. 1 with $300/4 = 75$ m length were considered 76%, 100% should be 98.5 m what is 50% of the 197 m. The broken line on the figure with $r/R = 0.5$ has a small deviation from the potential lines around it, so the potential along this circle is nearly constant (varies between 54% and 56%). So, in the case of 4 or more pipes, the field out of the $R = 197$ m circle does not influ ence the flow pattern in an observable way. In the case of two pipes instead of the circle a longer shaped boundary condition was applied with similar width.

However, by the density of potential lines on Fig. 1 one can conclude that the infiltrating discharge over unit length is really great at the outer end of the pipe, while along the pipe in the direction of the shaft it strongly decreases. The former would be worth for a more detailed examination, as this place is the main source of sanding. But the figures of potential distribution cannot be evaluated numerically with a proper accuracy, that is why instead of further detailing, the results of the direct discharge measurements are presented.

The discharge of the radial well, as a function of the number of pipes (totally perforated) compared to the discharge of a 10-piped well can be seen on Fig. 2. In an n-piped radial well, each pipe with the length of $l_{t,i}$ the total

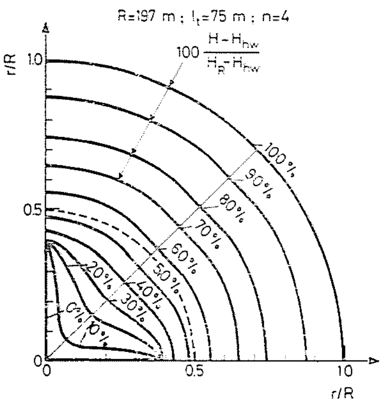

Fig. 1. The potential distribution in the case of a 4-piped radial well

discharge flowing through the cross section at l_n distance from the shaft is Q_n. On Fig. 2 the ratio of this discharge and Q_{10t}, the total discharge infiltrating along all the length of the pipes of a 10-piped well is represented. In the case of a 10-piped well if $l_n/l_{nt} = 0$ the curve crosses the axis of the relative discharge at the value of $Q_n/Q_{10t} = 1$, while the wells with a smaller number of pipes have a relative discharge being theoretically higher.

By the general evaluation of Fig. 2 it can be established that under similar or identical boundary conditions, the increase of the number of pipes decreases the discharge to be gained. It is well shown on Fig. 3. To some extent this is balanced by the friction loss of the pipe decreasing by the growth of the number of pipes, too. But if the friction loss is not great, even at small number of pipes, this statement is of no importance.

The numerical deviation of the discharge of a 4 and a 10-piped well compared to that of a 6-piped one is less than $\pm$ 6%. So it can be suggested that in many cases of the practice the number of pipes to be applied can be decided considering other points of view.

Fig. 4 shows the effect of the ratio of perforated length l_p and the total length l_t on the discharge in the case of a 4-piped well. Q_{4t} is the whole discharge of the 4-piped well with totally perforated pipe, Q is the discharge of a partly perforated 4-piped well at an arbitrary cross section. One can see that omitting the perforation at the part near the shaft has just a slight influence in the beginning. Limiting the perforation only to the outer 40% of the pipe results in

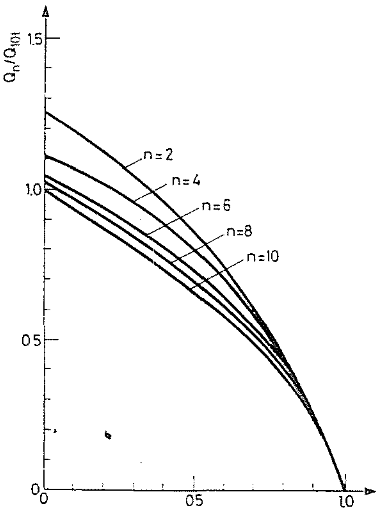

Fig. 2. The discharge flowing through the cross section l_n of a pipe with a length of l_{nt} compared to that of a 10-piped well

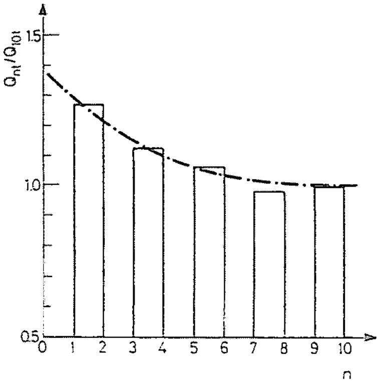

Fig. 3. The discharge of n-piped wells compared to that of a 10-piped well

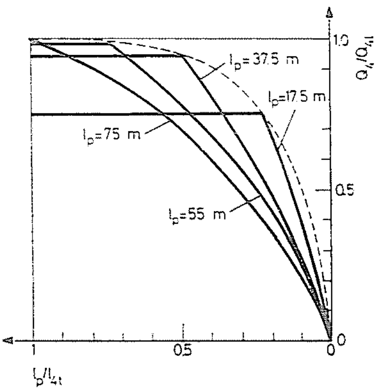

Fig. 4. The effect of the perforated length l_p on the discharge of the well ($n = 4$)

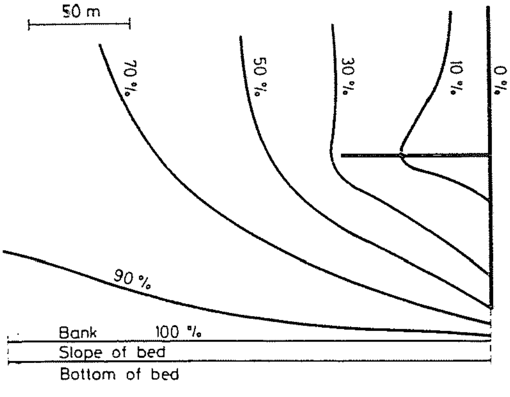

Fig. 5. Potential distribution (piezometric pressure difference) at the lower horizon of the cover layer

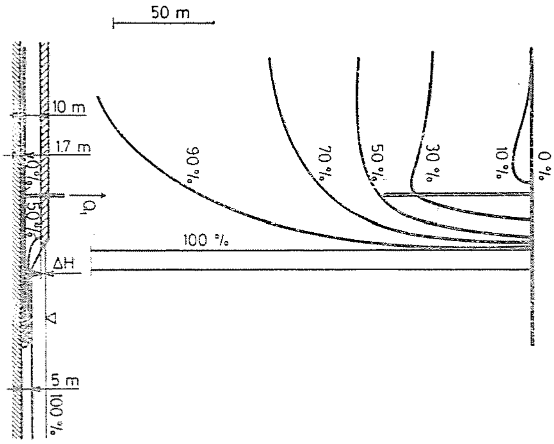

Fig. 6. Potential distribution (piezometric pressure difference) at the lower horizon of the cover layer. Plan and cross section through a pipe

10% decrease in discharge compared to Q_{4l}. 50% perforation yields 95% of Q_{4l} discharge obtained with total perforation.

In the case of unchanged demand on discharge perforation can be reduced if the number of horizontal pipes grows, and should be grown if the number of pipes decreases. No detailed studies have been carried out in this field, but in our opinion, in the case of 95% water demand the number of pipes does not influence the desirable perforated length more than $\pm$ 10% of the total length.

It has to be mentioned that a *l*-piped well must be perforated at both ends (i.e. both at the shaft and at the opposite end).

2.2. *Examination of the radial wells near colmated and uncolmated river beds*

These examinations were done with 4-piped radial wells. Their arrangement can be seen on Figs 5 to 10. On Figs 5, 7 and 9 the horizontal pipe does not reach under the river bed (the distance between the shaft and the central line of the bank slope is 97 m), on Figs 6, 8 and 10 the pipe is partly under the river bed (the distance between the shaft and the central line of the bank slope is 33 m).

The potential distributions at the lower horizon of the cover layer (at the upper horizon of the aquifer) are shown on Figs 5 and 6. On Figure 6 a profile is presented making the arrangement clearer. The discharge distributions coming from above data after detailed measurements are given on the further figures, where for the sake of simplification the coefficient of permeability was $k_0 = 1$ cm/s and the depression head was $\triangle H = 1$m. It is to be noticed, however, that these values result already in too high velocities in the horizontal pipes.

Figure 7 shows a case without colmation. One can see along the pipes the infiltration over unit length $q(l)$, and its summation curve $Q(l)$ from the end of the pipe. Among the pipes with Roman numbers, Nr. I in the direction of the river bed is the most active. it takes 42% of the total discharge that is nearly as much as the discharge of pipes Nos II and IV together (49%) built parallel with the river bed. Pipe Nr III at the opposite side of the river bed takes just 20% of the discharge of pipe Nr I that is about 6% of the total discharge. Its omission could hardly be noticed as the discharge over unit length of the neighbouring pipes near the shaft would increase.

The infiltration over unit length of the bank $q_p(s)$ has a peak around pipe Nr. I. On the basis of the summation curve the length of the bank can be determined which gives e.g. 90% of the total discharge (cca 380 m) with other words it gives data for the active zone of the well without colmation and for the reasonable density of wells, as well.

Figure 8 is also a case without colmation but with a pipe partly under the river bed. The produced discharge is 2.5 times higher than in the former case.

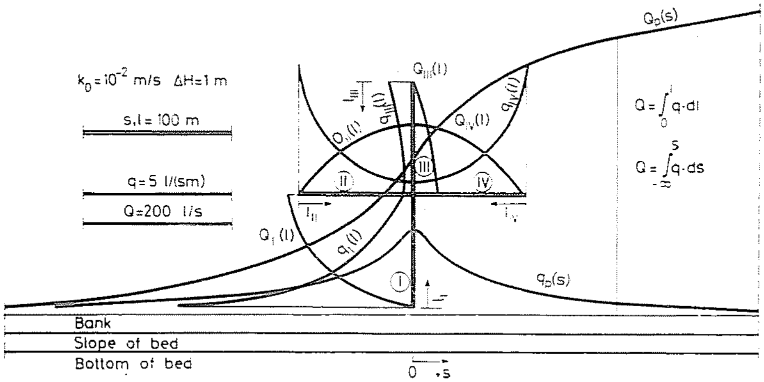

Fig. 7. Distribution of discharge over unit length along the bank and the pipes and their summation curves. No colmation

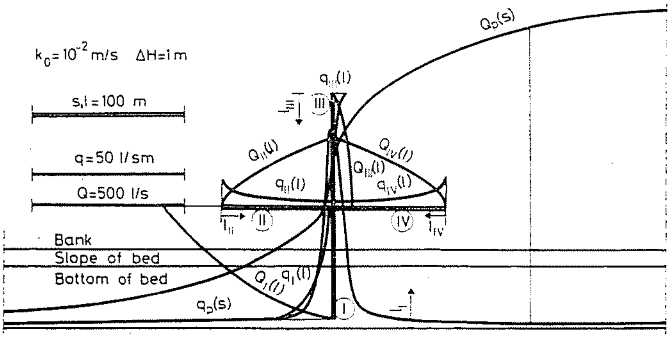

Fig. 8. Distribution of discharge over unit length along the bank and the pipes and their summation curves. No colmation

It is typical that the part of the river bed giving most of the discharge gets shorter, because the pipe under the river bed intensively draws off the nearest bottom zone 3.3. m above the pipe.

Figure 9 shows the effects of an arrangement with pipes not reaching the river bed and with a colmated crust uniformly 1 m thick above the surface of the river bed. The coefficient of permeability of the crust is $k_C = 1.57.10^{-4}$ m/s that is 1/64th part of the original k_0. The curve of the intensity of the bank infiltration $q(s)$ is more uniform, the summation curve is less steep which means that comparing with the uncolmated case, the active zone considerably grows. The assumption of uniform colmation is not a practical case, but suitable to show the effect of colmation on the growth of the active zone resulting (in the case of a given k_c) just in a moderate decrease in discharge. (In this case comparing with the one on Fig. 8 the discharge is 70%.)

On Figure 10 a colmation better approximating reality is supposed. In this case, too, the colmation is uniform, but only along a finite length (290 m) of the river bed (though on the total width of the bed). One can see the sudden change of infiltration at the end of the colmated part. The discharge volume is between the two former cases

It must, however, be remarked that in the case of colmation the effects of surfaces not contained by the analogous model cannot be fully neglected that is why the real decrease of discharge is smaller than that mentioned above.

One can see that the above introduced electric analogous examinations are suitable to numerically solve any seepage problem in space. Based on experiences such a model can be built that can take into consideration the colmation of the river bed with any size and distribution, between the values of $k_c/k_0 = 0.001$ to 1.0 referring to a layer of 1m thickness so that on the whole surface of the river bed the velocity distribution of the infiltration can be measured (above only the discharge over unit length has been measured).

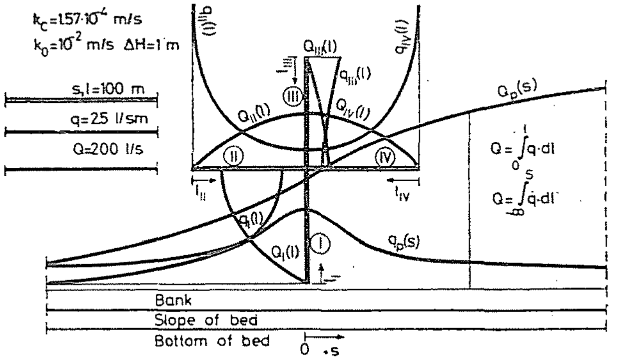

Fig. 9. Distribution of discharge over unit length along the bank and the pipes and their summation curves. Uniform colmation over the whole surface of the river bed

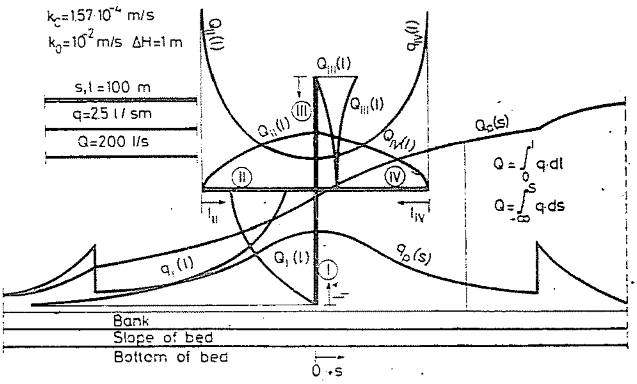

Fig. 10. Distribution of discharge over unit length along the bank and the pipes and their summation curves. Uniform colmation over a part of the river bed

The free surface of the seepage can also be determined and the friction loss along the horizontal pipes can be taken into account, too. By all means, it is advisable to limit the studies to well-known typical cases for which this paper provides some assistance.

Conclusions

— Hydraulic difference between the different vertical situations of the horizontal pipes could not be proved, but it is logically clear that highest capacity of pipe can be achieved if it is in or a little bit above the middle of the most depressed water layer. The upwards arched pipes under practical conditions approximate this state "by themselves".

— The capacity of a radial well is proportional to the 0.87th power of the layer.

— Further investigations would be advisable to determine the velocity distribution at the outer end of the pipe, as it can be the main source of sanding.

— The increase of the number of horizontal pipes with the same total length (in infinite space) causes a slight decrease in the discharge which is partly balanced by the friction loss of the pipe. Therefore, determining the number of pipes, other not hydraulic aspects can be taken into consideration.

— Limiting the perforation just for the outer half of the length of the pipe yields about 5% reduction in the discharge, despite that in the case of total perforation the inner half of the pipe takes 30—40% of the total discharge.

— In the case of a radial well, sited near a river bed, the pipe opposite to the river bed can be omitted without any considerable decrease in discharge.

— The radial well near a river bed takes the most part of the water from the nearest part of the bank, but the connection between the bank and river bed infiltration and the situation of the well needs further studies.

— The horizontal pipe reaching under the river bed considerably increases the discharge, but takes most amount of the water from a rather short part causing eventually a rapid colmation.

— If it is necessary for some reason to make the bank infiltration more uniform (to soften the peak, to extend the utilized part of the bank), it seems to be advantageous to apply two longer, and one shorter (middle) pipe. The angle between them is cca. 60—60° and they approach or reach under the bank nearly in the same extent.

— Colmation extends the influence of the well on a longer section of the river bed so that its effect to decrease the discharge develops relatively slowly.

— To clear up the development of physical, chemical and biological colmation is by all means necessary to forecast, perhaps to reduce the effect of colmation on the "ageing" of wells.

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