Laboratory Steady-State Flow Tests of Round Dual Infiltration Recharge Well with Filter Layer

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Abstract. The structure, characteristics and the steady-state flow recharge tests research of the new round dual recharge well with filter layer are introduced. An infiltration recharge well with filter layer is composed of a recharge pool functioning as an inverted layer and an artificial recharge well located at the bottom center of the recharge pool. The round dual infiltration recharge well with filter layer is based on analyses of the problems of the existing infiltration recharge wells with filter layer. In this study, a laboratory steady-state flow recharge test device has been developed. Laboratory steady-state flow tests are performed to compare the existing infiltration recharge well with filter layer, a round dual infiltration recharge well with filter layer and an artificial recharge well. The results indicated that compared to the existing infiltration recharge well with filter layer, the round dual infiltration recharge well with filter layer has a larger single-well recharge volume and stronger anti-rush ability. With an increasing number of tests, the single-well recharge volumes gradually decrease and stabilize.

1. Introduction
Groundwater recharge is an important technique for increasing the rain and flood resource utilization rate and improving the water shortages condition. The infiltration recharge well with filter layer consists of a recharge pool and an artificial recharge well that is placed at the bottom center of the recharge pool. The recharge pool is a square soil pit that has an upper part that is larger than the lower part. Sand and gravel are backfilled to the soil pit as a two-stage filter material.

Regarding research considering the blocking of recharge wells, Huang Xiudong¹ used a sand column to simulate the clogging process of recharge wells surrounded with sand in the well recharge process and analyzed the physical and biological clogging that may occur during the well recharge process. N. Phien-uej² analyzed blockages caused by air in the water, the chemical incompatibility between the water and natural groundwater, and suspended particles in the water.

Regarding research considering the recharge capacity of recharge wells, A.K.Rastogi³ studied the effect of the shape of the recharge pool on the recharge volume and analyzed the recharge effect of rectangular, square, hexagonal, circular, triangular and other shapes of recharge pools using the Galerkin finite element method. He concluded that the recharge volume of a rectangular tank is the largest under the conditions of equal area and a constant recharge rate, among other identical conditions. Li Wanglin⁴ analyzed an existing infiltration recharge well with filter layer and found that the main performance aspect with regard to recharge clogging is the deposition and blockage of the surface of the recharge pool, which reduces the service life of the infiltration recharge well with filter layer. The ability to resist water scouring is relatively low, and the recharge pool is easily destroyed.

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The head loss of the recharge pool is rather high, and the flow capacity is low, which greatly reduces the recharge ability of the infiltration recharge well with filter layer. Li Wanglin[5] explored ways to improve the recharge ability of an infiltration recharge well with filter layer. The infiltration recharge of the infiltration recharge wells with filter layer was divided into vertical seepage and horizontal well flow, and the quantitative calculation formula for the single-well recharge volume based on Darcy's law was derived.

2. Round Dual Infiltration Recharge Well with filter layer

A new type of infiltration recharge well with filter layer has been developed with the aim of improving upon the deficiencies of existing infiltration recharge wells with filter layer. The new design is based on the fact that the low capacity of the recharge pool in the existing infiltration recharge well with filter layer affects the recharge volume. The new recharge well design should be focused on improving the infiltration capability of the recharge pool and the anti-deposit and anti-flushing capabilities of the recharge pool. Therefore, the new round recharge well with filter layer retains the structure of an ordinary recharge well, but the recharge pool is lifted up from the underground to the ground level and the one-side infiltration is replaced by multi-surface infiltration. A new round infiltration recharge wells with filter layer have been developed. The round dual infiltration recharge wellhead with filter layer has two symmetrical tops, a lateral medial surface and a bottom surface that can serve as an inlet (see Figures 1a-d).

(a) schematic diagram of the vertical section   (b) round dual recharge wellhead

(c) round dual A-A profile         (d) round dual B-B profile

Figure 1 recharge wellhead; 2 lateral wall; 3 geotextile; 4 bottom floor; 5 lateral wall orifice; 6 medial wall orifice; 7 recharge wells; 8 filter material

Figure 1. Structural diagram of the round infiltration recharge well with filter layer

Compared to the existing recharge wells with filter layer, the round dual infiltration recharge well with filter layer has the following features:

(1) The recharge pool is changed to a recharge wellhead and placed on the ground. The top surface, outer side, inner side and undersurface, which can be flooded, can increase the inflow section area of the wellhead, and the wellhead has improved desilting capabilities.

(2) Reinforced concrete is used as the material to improve the resistance to being rushed.

(3) The surface of the recharge wellhead is covered with a layer of geotextile that can effectively filter granular impurities that exist in the water and also reduce the amount of sand and gravel materials used. The geotextile is easy to repair and replace.
(4) The bottom of the recharge wellhead has been made into an impermeable body, which can prevent inferior water flow into the aquifer when the water level is lower at the beginning stage of storm water from rainfall.

(5) If the river is polluted, the outer layer of the geotextile has an added geomembrane as an impermeable layer, which can prevent polluted river water from recharging to the aquifer.

3. Steady-State Flow Test of a Round Dual Infiltration Recharge Well with filter layer

Infiltration recharge wells with filter layer are often used in the aquifer, the upper part of aquifer is clay and the lower part of aquifer is sand. When the underground water level drops, and the water level is lower than the bottom elevation of water-resisting plate, the original confined aquifer translate into the unconfined aquifer. When the groundwater recharge, the aquifer is shown as a confined-unconfined aquifer, the aquifer is confined aquifer near the recharge well and the aquifer is unconfined aquifer which is far away from the recharge well. The steady-state flow recharge test of a fully penetrating infiltration recharge well with filter layer in the confined-unconfined aquifer is conduct.

3.1 Test device and sample preparation

The laboratory recharge test device is a cuboid made of organic glass materials with dimensions of 1.8 m × 0.8 m × 1.3 m that can simulate the steady-state flow recharge test of the half fully penetrating infiltration recharge well with filter layer and the partial penetrating infiltration recharge well with filter layer. The test device is shown in Fig. 2.

![Figure 2.](image)

**Figure 2.** The experiment device for recharge in the laboratory

The laboratory recharge test device consists of four parts: the water supply system, drainage system, recharge system and measuring system.

The recharge system is composed mainly of a recharge flume, a recharge well, round dual wellheads, a rectangular vessel and a regulating tank. The recharge flume and rectangular vessel are used to simulate the natural river channel and aquifer, respectively, and the regulating tank is used to control the groundwater table around the recharge well. The recharge well is made of organic glass, and the radius is 10 mm. Half of the recharge well is stuck in the middle of one side wall of the rectangular vessel. Round dual recharge wellheads are made according to the ratio of 1:25, and all are taken halfway to capacity. The open porosity of the inflow water section is approximately 20%, round dual wellhead have a height of 60 mm, an outer diameter of 40 mm, and an inner diameter of 20 mm. By comparative analysis, the original recharge pool model is established at a scale of 1:25 and similarly taken to half capacity, and its bottom sizes and top sizes are 40 × 20 mm and 40 × 80 mm rectangles, respectively.

The measuring system consists of a water level measurement system and flow measurement system. The water level measurement consists of a water level scale on the flume, a water level scale on the regulating tank, and a piezometric tube. Flow measurement consists of inlet flow measurement and outlet flow measurement. Twenty piezometric tubes that are used mainly to measure the groundwater level in the aquifer are arranged at the bottom of the rectangular vessel according to a layout of horizontal, vertical and diagonal lines.
3.2 Recharge test
Three groups of recharge tests were intended to simulate the steady-state flow of the fully penetrating well in the confined-unconfined aquifer: (1) the steady-state flow recharge test of the artificial recharge well with the recharge well and no recharge wellhead or recharge pool; (2) the steady-state flow recharge test of the existing infiltration recharge well with filter layer that was simulated with the existing recharge pool, in which sand and gravel were employed as a two-stage filter material; (3) the steady-state flow recharge test of the round dual infiltration recharge well with filter layer.

To maintain the stability of the ambient groundwater level, a gravel drainage belt was employed at the bottom of the box wall, which was on the opposite side of the well. The outlet of the drainage belt was connected to the regulating tank of both sides to make the groundwater level correspond to the water level of the regulating tank. During the test, the recharge water level in the flume was approximately 92 cm (taking the bottom of the container as the 0 cm benchmark elevation), and the ambient groundwater level was 20 cm. The water flow into the flume came from one side of the tank and through the recharge well with filter layer. A part of the water infiltrated into the well through the wellhead or the recharge pool, and the remainder was discharged from the other side of the tank. The water of the recharge well flowed into the sand layer in a horizontal flow. The water in the sand layer flowed into the regulating tank on both sides. The drain valve of the regulating tank was opened to stabilize the water level of the regulating tanks on both sides at 20 cm, and the discharged volume from the tank on both sides in the unit time was equal to the single-well recharge volume of the recharge well.

The end standards of the recharge test were as follows. The recharge volume was successively measured three times, and the recharge test was ended when the difference in the recharge volume in every two successive measurements was not greater than the recharge volume of the latter (the second time in two successive measurements) of 5%. A parallel test was conducted for each type of recharge test.

The final measurement result was the average of the last measurements of the single-well recharge volume.

3.3 Test results
Table 1 shows the single-well recharge volumes of the steady-state flow test of a fully penetrating well in a confined-unconfined aquifer under the condition that the recharge head was 92 cm in the flume and the water level of the regulating tank was 20 cm. The groundwater level was measured by piezometric tubes.

| Name of Recharge Well                              | Recharge Volume (L/min) | Flow Section Area of Well Head (cm²) |
|---------------------------------------------------|-------------------------|--------------------------------------|
| Artificial recharge well                          | 19.82                   |                                      |
| Existing infiltration recharge well with filter layer | 3.05                    | 32.00                                |
| Round dual infiltration recharge well with filter layer | 15.68                   | 37.23                                |

4. Analysis and Discussion

4.1 Groundwater level
Fig. 3 shows that comparison of groundwater level between the existing recharge well with filter layer and the round dual recharge well with filter layer. Figure R is the distance from the center of the
piezometric tubes to the recharge well. Under the same conditions concerning the aquifer structure, recharge water level and surrounding underground water level, the groundwater level of the round dual infiltration recharge well with filter layer, is higher than the groundwater level of the existing infiltration recharge well with filter layer. These data indicate that the recharge water flow into the recharge well through the recharge pool or the recharge wellhead, the comprehensive head loss of the existing recharge pool is larger than the comprehensive head loss of the round dual recharge wellhead.

![Figure 3. Measured groundwater level](image)

4.2 Single-well recharge volume

The following conclusions can be drawn from Table 1 and Fig. 3:

1. The single-well recharge volumes of the existing infiltration recharge well with filter layer are only 15.4% of the recharge volumes of the artificial recharge well because the recharge volumes of the existing recharge well are commonly controlled by the infiltration capacity of the recharge pool and the recharge capacity of the recharge well. The recharge capacity of the round dual recharge well is higher and the infiltration capacity of the existing recharge pool is lower, influencing and restricting the single-well recharge volumes of the existing recharge well with the filter, indicating that the structure size of the recharge pool does not match the recharge well and that the design is not reasonable.

2. The round dual infiltration recharge well with filter layer are 79.1% of the recharge volumes of the artificial recharge well, indicating that the infiltration volumes show a large improvement. The round dual infiltration recharge well with filter layer improves the situation in which the structure size of the recharge pool does not match the recharge well and that the design is not reasonable.

3. Compared to the existing infiltration recharge well with filter layer, the single-well recharge volumes of the round dual infiltration recharge well with filter layer increases by a factor of approximately four, which effectively improves the recharge capability of the infiltration recharge well with filter layer.

4.3 Influence of recharge test times on the single-well recharge volume

The first recharge test was conducted to obtain the first single-well recharge volumes of the round dual infiltration recharge well with filter layer under the condition that the water level of the recharge pool is 92 cm and the water level of the regulating tank is 20 cm. After 10 min, the second recharge test was carried out to obtain the second single-well recharge volumes of the round dual infiltration recharge well with filter layer. By analogy, the same recharge tests were carried out 12 times in a row. Fig. 4shows the curves between the single-well recharge volume, Q, and the recharge test time N in a successive recharge test.

![Figure 4. Curves between the single-well recharge volume Q and recharge test time N](image)
Figure 4 illustrates that the single-well recharge volumes of the initial test were the largest for the successive tests of the round dual infiltration recharge well with filter layer. With an increase in the test times, the single-well recharge volumes gradually decreased and tended to stabilize. The stable volumes were approximately 60.2% of the initial volumes.

5. Conclusions
The following conclusions are drawn from the above tests and analyses:

1. Compared with the artificial recharge well, the recharge pool and recharge wellhead influence the recharge capacity of the infiltration recharge well with filter layer. The single-well recharge volumes of the infiltration recharge well with filter layer are reduced to different extents.

2. Compared with the existing infiltration recharge well with filter layer, the round dual infiltration recharge wells with filter layer have a large single-well recharge volume, which has a stronger anti-rush ability and reduces the amount of gravel material used.

3. Compared with the existence recharge infiltration recharge well with filter layer, the design of the round dual recharge wellhead is reasonable.

4. For a continuous recharge test, the initial recharge test of the round dual infiltration recharge well with filter layer has the maximum single-well recharge volumes. As the number of test runs increases, the single-well recharge volumes gradually decrease and tend to stabilize.

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