Laboratory Recharge Tests of Square Dual Anti-Filtration Recharge Well

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Abstract. The anti-filtration recharge well is the most important part of the groundwater recharge project. It is generally composed of a recharge well and a recharge pool. The main problems of the existing anti-filtration recharge well are low recharge capacity and blockage. In this paper, the structure of recharge pool is improved and optimized, and a new square dual anti-filtration recharge well is designed, the laboratory steady flow recharge tests were performed. The conclusions are as follows: (1) Under the same test conditions, the recharge volume of ordinary recharge well, existing anti-filtration recharge well, new square dual anti-filtration recharge well were 7.75, 1.05, 4.64 L/min, respectively. The recharge volume of square dual anti-filtration recharge well is about 60% that of the ordinary recharge well. (2) Compare to the existing anti-filtration recharge well, the recharge volume of square dual anti-filtration recharge well is increased by about 440%. (3) During the repeated laboratory recharge tests of the square dual anti-filtration recharge well, the largest single well recharge volume was appeared in the first time. With the increase of recharge test times, the single-well recharge volume gradually decreased and tended to be stable.

1. Introduction
In order to effectively use the rainwater resource and alleviate the shortage of water resource in water-deficient areas, people began to recharge the groundwater [1]. Therefore, recharge projects have been built in rainwater-flood resource utilization areas at home and abroad. The most common recharge facilities are recharge well [2]. A large number of recharge wells have been built to recharge groundwater in the Jiaodong Peninsula of Shandong Province.

The Jiaodong Peninsula in Shandong Province is a low hilly area with a per capita water resource of 291.3 m³, which is a serious water shortage area. 70-80% of the annual rainfall occurred in July-August in this area. The phenomenon of dry up of the river appears in the dry season. During the flood season, a lot of rain and flood could not be utilized and into the sea. The utilization rate of water resources was only 30%. In order to utilize rainwater resources effectively, a number of groundwater recharge projects have been constructed in Shandong Peninsula, of which the anti-filtration recharge well is the most commonly used recharge facility [3]. Anti-filtration recharge well is a special kind of recharge well with certain water purification capacity, which is generally arranged in the river channel or irrigation canal. The existing anti-filtration recharge well are composed of a ordinary recharge well and a recharge pool. The recharge pools are filled with two layers of filter materials, gravel and sand,
so that they can filter particles and impurities in water [4]. When the water flows through the recharge pool, the river water infiltrates into the recharge well and transforms into groundwater. However, during the later operation of the anti-filtration recharge wells, with the increase of operation time, the plugging problem will occur, resulting in the gradual decline of recharge capacity [5].

Based on the analysis of the problems existing in the existing anti-filtration recharge wells, a new square dual anti-filtration recharge well is designed, and a laboratory recharge test equipment is developed, the laboratory recharge tests of ordinary recharge well, anti-filtration recharge well and square dual anti-filtration recharge well are carried out, which has important practical significance.

2. Square Dual Anti-Filtration Recharge Well

At present, the main problems of anti-filtration recharge wells are as follows: (1) The recharged pool has fewer flow section area and the recharge pool has low recharge capacity; (2) Anti-filtration recharge well are easy to be clogged and destroyed by water, which has a low service life; (3) The construction of anti-filtration recharge well requires backfilling a lot of sand and gravel, which consumes more building materials and has higher construction costs. These problems have seriously hindered the further development of the rainwater recharge.

In view of the existing problems of the existing anti-filtration recharge well, on the basis of retaining the original recharged well structure, the recharged pool is raised from the underground to the ground, and the original soil pit is changed into a recharge wellhead of hard materials. And the way of infiltration from the one-side infiltration is changed into multifaceted infiltration, which can prevent deposition and increase the flow section area of infiltration. In addition, geotextiles with large permeability coefficient are used to replace sand filter layer at wellhead, which not only has the function of filtration, but also is convenient for maintenance and replacement. The square dual anti-filtration recharge well has been designed, as shown in Fig. 1.

![Diagram of square dual anti-filtration recharge well](image)

**Figure 1.** Diagram of square dual anti-filtration recharge well

Compared with existing anti-filtration recharge wells, the characteristics of the square dual anti-filtration recharge wells are as following:
(1) The recharge pool, which is called the wellhead, is placed above the ground. The top, outside, inside and bottom surface of the wellhead can be infiltrated with water, which enlarges the area of the inflow section and improves the anti-deposition ability.

(2) The new square dual anti-filtration recharge wellhead adopts reinforced concrete and other hard materials to enhance the impact resistance.

(3) The new square dual anti-filtration recharge wellhead is covered with a layer of geotextile, which can filter impurity particles in the water and save gravel materials, and is easy to maintain and replace.

(4) The new square dual anti-filtration recharge wellhead is made impermeable in a certain height range at the bottom, which can prevent inferior river water of the low water level from being recharged into aquifer in the early stage of rainflood.

(5) If the river water is temporarily contaminated, a geomembrane can be added on the outside of the geotextile filter layer of the new recharge wellhead to prevent the contaminated river water from being recharged into the aquifer.

3. Laboratory Recharge Test of Square Dual Anti-Filtration Recharge Well

3.1. Laboratory Recharge Test

(1) Laboratory test equipment

The design of laboratory test equipment for anti-filtration recharge well mainly takes into account the following factors: (1) The laboratory test equipment should be able to simulate the actual recharge process of the recharge system, including the surface and underground parts. (2) The size of the laboratory test equipment should be proportional to the size of the field recharge system, and the components of the laboratory test equipment should be the same as the actual recharge system. (3) Transparent materials with good pressure resistance, corrosion resistance, waterproofing and sealing should be selected for the laboratory test equipment to observe the infiltration flow pattern and groundwater level of the recharged water. (4) The laboratory test equipment should be able to control the intake, discharge and groundwater level, so as to simulate the recharge process under different condition. The laboratory test equipment is shown in Fig. 2.

![Laboratory recharge test equipment](image)

**Figure 2.** Laboratory recharge test equipment

According to the design principle of the above laboratory test equipment, the main body of the test device is made of colorless and transparent plexiglass, and the main body is reinforced by a steel plate. The test equipment is a cuboid with a length of 1.8 m, a width of 0.8 m, and a height of 1.3 m. The equipment consists of a water supply zone, a seepage zone and a drainage zone, which can control the groundwater level and the recharge water level. The pressure measuring holes are formed in the
bottom plate of the test device, and the water level at different positions can be measured. The laboratory test equipment can better simulate the recharge process of the recharge system and can simulate fully penetrating well and partially penetrated well well.

In the Fig. 2, the water inlet and the recharge flume together form a water inlet area to simulate a natural river channel; The water outlet can control the water level of the recharge volume; The well pipe simulates the recharge well and forms a seepage zone together with the tank; The regulating tank is used to simulate the ground water, and the water outlet on the outer wall of the regulating tank can adjust the different groundwater level value. The water leakage holes are arranged at the partition board to ensure that the tank is communicated with the regulating tank.

Half of square dual anti-filtration recharge wellhead was made at a ratio of 1:25, the open porosity of the inflow water section was approximately 20%, the square dual anti-filtration recharge wellhead had a height of 60 mm with an side length of 40 mm. Half of the ordinary recharge well with a radius of 10 mm was glued in the middle of the rectangular vessel sidewall. For comparative analysis, a 1:25 original recharge pool model was made, half of which had a bottom size of 40×20 mm and a top size of 40×80 mm.

The surface of the test device is clay, the lower layer is sand, and the sand sample is made of natural river sand. The dry density of sand is 1.44~1.50g/cm³, and the permeability coefficient is 3.07~3.55×10⁻⁴m/s, its average particle size is 0.84mm, the unevenness coefficient is 3.20, and the curvature coefficient is 1.18.

(2) Experiment scheme

To simulate the recharge test of the fully penetrating well in confined aquifer, three kinds of recharge tests were planned: Scenario 1: The recharge test of the ordinary recharge well without wellhead; Scenario 2: The recharge test of the existing anti-filtration recharge well. Scenario 3: The recharge test of the square dual anti-filtration recharge well.

(3) Laboratory recharge test

The above test equipment is used to carry out the laboratory recharge test of the recharge well. The specific test steps are as follows:(1)Place the new recharge wellhead above the recharge well, so that the recharge wellhead permeable hole is higher than the recharge flume, and fill the gap with sealant to prevent the recharge water from flowing out of the gap, ensuring that the recharge water flows into the recharge well; (2) Close the water outlet valve of the recharge flume, open the water inlet valve of the recharge flume, and accumulate the water level of the recharge flume to 93cm; (3) When the water level in the recharge flume reaches 93cm, open the water outlet valve of the recharge flume, and adjust the water intake and water output, and the water level in the recharge flume is stable at 93cm. Open the regulating tank outlet valve to control the groundwater level to 25cm; (4) When the water level in the recharge flume and the groundwater level in the regulating tank is stabilized, the water level value in each pressure measuring tube is read and recorded; (5) While reading the water level of the piezometer tube, the water discharge of the outlet pipes of the two regulating tanks within 10 minutes is measured and recorded, and the volume of water output is equal to the recharge volume.

3.2. Test results

The single-well recharge volume of each recharge test is presented in Table 1. The groundwater level measured by piezometric tubes is shown in Fig. 3.

| Name of Recharge Well           | Flow Section Area of Wellhead(cm²) | Recharge Volume(L/min) |
|---------------------------------|------------------------------------|------------------------|
| Ordinary recharge well          |                                    | 7.75                   |
| Existing anti-filtration recharge well | 32                                  | 1.05                   |
| Square dual anti-filtration recharge well | 52                                  | 4.64                   |
We can see from Table 1 and Fig. 3:

1) Under the same test conditions, the single well recharge volume of the existing anti-filtration recharge well is only 13.5% of that of the ordinary recharge well, and the single well recharge volume of the square dual anti-filtration recharge well is 60% of that of the ordinary recharge well.

2) Compared to the existing anti-filtration recharge well, the single-well recharge volume of the square dual anti-filtration recharge well increasing by about 440%, which indicated that the recharge capacity of the anti-filtration recharge well is greatly improved by the new recharge wellhead.

3) Under the same test conditions, the groundwater level of the ordinary recharge well is the highest, that of the new square dual anti-filtration recharge well is the second, and that of the existing anti-filtration recharge well is the lowest.

4. Analysis and Discussion

4.1. Groundwater Level Curve

The measured groundwater level of three kinds of well was presented in Fig. 3, under the same conditions, the groundwater level of ordinary recharge well is highest, followed by the square dual anti-filtration recharge well, existing anti-filtration recharge well. These data indicate that the comprehensive head loss of the existing anti-filtration recharge well is largest during the recharge test, the square dual anti-filtration recharge well has a relative small comprehensive water head loss and has a larger recharge volume.

4.2. Single-Well Recharge Volume

During the recharge test, the flow section area of the square dual anti-filtration recharge wellhead and existing anti-filtration recharge pool were 52 cm² and 32 cm² respectively. However, the single-well recharge volume of the square dual anti-filtration recharge well and existing anti-filtration recharge well correspondingly were 4.64 L/min and 1.05 L/min, compare the existing anti-filtration recharge well, the recharge volume of the square dual anti-filtration recharge well increased by about 440%. The reason is as follows: compare to the existing anti-filtration recharge well, the water just can be infiltrated to well in one-side, However, the water can be infiltrated into the square dual anti-filtration recharge well in multi-surface infiltration, the inflow section area of the wellhead is increased and a higher recharge volume is got.

4.3. Influence of Recharge Test Times on Single-Well Recharge Volume

Taking the square dual anti-filtration recharge well as an example, the relation curve between the single-well recharge volume Q and the repeated recharge test time N is presented in Fig. 4.
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Figure 4. Curve between the single-well recharge volume Q and repeated recharge test time N

We can see from Fig. 4: the single-well recharge volume arrived the largest value in the first recharge test. With the increasing of recharge test times, the single-well recharge volume decreased gradually and tended to be stable, and the stable single-well recharge volume was about 89% of the single-well recharge volume in the first time.

The reasons for this phenomenon are as following: during the laboratory recharge test, the adapted recharge water was not pure water but tap one. When water flow flowed from square dual anti-filtration recharge wellhead into the recharge well, and then into the water-bearing sand layer, the recharge water contained a certain amount of closed air bubbles and fine silt particles, which are brought to the sand layer with the water flow around the well, formed a blockage and reduced the single-well recharge volume. Thus, the stable single-well recharge volume was generally lower than the first one.

5. Conclusion
Through the recharge test and analysis in this paper, we find the following conclusions:

When the initial water level was 25 cm and recharge water level was 93 cm, the single-well recharge volumes of the ordinary recharge well, the existing anti-filtration recharge well, the square dual anti-filtration recharge well is 7.75, 1.06, 4.64 L/min, respectively. The single-well recharge volume of square dual anti-filtration recharge well was about 60% of the single-well recharge volume of the ordinary recharge well.

Compare to the existing anti-filtration recharge well, the single-well recharge volume of square dual anti-filtration recharge well is increased by about 440%

During the repeated laboratory steady-state flow recharge tests of square dual anti-filtration recharge well, the single-well recharge volume arrived the largest value in the first time. With an increasing number of recharge tests, the single-well recharge volume decreased gradually and tended to be stable finally.

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