The Principle of Density Differences Drive Geothermal Water to Move and the Short Range Recharge Model of Geothermal Water in Hilly Area

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Key words: principle, density differences from different temperatures, geothermal water movement, coexistence mechanism of recharge and discharge (hot springs) zones can be at same altitude, the short range recharge model of geothermal water

ABSTRACT
The thermal reservoir of a geothermal well in a rift subsidence basin with depth of 2148m belongs to the lower Tertiary sandstone. Pumping test results: the initial water table is 8.7m under ground, the initial water temperature is 50°C; in the 80m³/h pumping conditions for 34h, the water temperature is 56°C, water table is 5.2m under ground, e.i. upthrow of 2.5m; 2 minutes later, the well begins to flow itself and water temperature is 61°C, water outflow yield is about 60 m³/h; after 46 hours, the water outflow yield is to the max 90m³/h and for 8h while the water head is 9.2 m above the ground and the water temperature is 67°C. The authors put forward the idea that the movement mechanism of the groundwater is caused by the density differences from different temperatures. Based on this idea, the authors propose the short range recharge model of geothermal water in flat terrain hilly area. The model explains the coexistence mechanism of recharge and discharge (hot springs) zones can be at same altitude. Considering the temperature is an important driving force of groundwater movement, the paper puts forward and demonstrates that the hot springs can expose at higher lands while the recharge zone being situated lower lying areas.

1. GEOTHERMAL WELLS OVERVIEW
The geothermal well with depth of 2148m and the ground elevation of 372m is located between State Road 108 and the Taiyang village,Yangcun town,Hejin city,southwest of Shanxi Province,China(Figure 1), 10km west of the Yellow River[1]. The area is alluvial plain,which is located in the southwestern tip of the Lvliang Rocky Mountains where falls into continental arid and semi arid climate with average rainfall of 483.2mm. The Yellow River average annual flow is 766.1m³/s. The geological structure position is at the boundary of Lvliang uplift and Fenwei graben. The concealed tectonic structures of Himalaya orogeny create the conditions for the formation of geothermal water that occurs at the lower tertiary with depth of 1500m-2148m. The stratigraphic conditions are shown in Table 1.

![Figure 1 Taiyang Village Traffic Location Map](image)

Table 1 Geothermal well stratigraphic and lithologic profile

<table>
<thead>
<tr>
<th>Burial Depth(m)</th>
<th>Stratigraphic Era</th>
<th>Lithology</th>
<th>Caliper Casing and Filter Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~410</td>
<td>Q</td>
<td>clay and fine sand interbed, every sand layer is very thin. Loose lithology structure as a whole.</td>
<td>0~191.62m, C 445mm, C</td>
</tr>
<tr>
<td>~1050</td>
<td>N</td>
<td>loose clay and sand interbed, local with a small amount of gravel, color is gray or light gray.</td>
<td>339.7mm×9.65mm,total of</td>
</tr>
</tbody>
</table>
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| ~1216 | loose fine sand or medium sand interbed, light color or khaki with a small amount of mottled sandstone coarse particles interlayer |
| ~1480 | half cementation or cementing loose bed, color motley but is given priority to with brunet. Lithology is given priority to with angular metamorphic rock, sandstone and limestone. |
| ~1750 | mixed gravel layers with fine sand interlayer, includes coarser sandstone, metamorphic rock and limestone particles. |
| ~1890 | half cementation or cementation sand gravel layers, gravels are given priority to with angular and motley metamorphic rocks which contains more quartz particles with depth |
| ~2148 | gravel with flake mudstones, and particle on slightly thin, more limestone composition in gravels with depth |
|       | 191.62m; 170.44m-1050.97m.  
|       | 311mm, 244.5mm×8.94mm total of 880.53m; 8.94mm total of 880.53m; |
|       | 1019.96m-1910.12m.  
|       | 215mm, 177.8mm×8.05mm total of 890.16m; 8.05mm total of 890.16m; |
|       | Including below 1500 m in sand or gravel layer into the filter tube  
|       | 177.8 mm under the total length of 171.30 m;  
| ~1750 | 1910.12m-2148.00m.  
|       | 152mm, open hole |

Works of flushing well, pumping test, etc are doing conventionally when the final construction of the hole.

Well flushing time: From 00:00, August 3, 2013, to 12:00, August 4, 2013. Well flushing with large volume pumps punching, large flow high drawdown drainage (90~95m³/h flow control) mode for 36h while sand and water are clean.

Pumping test begins after well flushing for 10h, from the August 4, 2013, 22:00 to August 6, 2013, 8:00. The total time of pumping is 34h ,the pumping flow rate is 80m³/h, the initial water depth is 8.7m (after the well flushing), pumping stable water depth is 5.2m, water level rises 2.5m , the water temperature is 56 °C.

After stop pumping 2min water is artesian flowing and begins the dewatering test.

The dewatering test since August 7, 2013, 8:00 to August 9, 2013, 12:00 for 54h. The water flow from the beginning of 60m³/h up to 90m³/h and keeps stable for about 8h while water temperature is 67°C. Then closing well and monitoring well pressure is 0.092Mpa up the ground. Then the well pressure decreases gradually to zero after 9.5h(Figure 2).

![Figure 2](image-url)  
*Figure 2  well pressure decreases gradually with water temperature after the dewatering test*
The water quality type is Cl·SO\textsubscript{4}·Na, TDS is 2341.33mg/L and content of F is 3 mg/L.

After the pumping and dewatering test, the water level is not lower but upper, until the the end of the "relatively stable" 8h while the pressure is 92Kpa higher than the ground. So the water level rises 17.9m higher than that after well washing. This result is abnormal for usually underground water wells, but is normal for geothermal wells in this area. However, according to the general knowledge or geothermal standard, it is difficult to calculate the hydrogeological parameters of the corresponding heat reservoir and more difficult to calculate the index of corresponding regional geothermal resources storage quantity as well. So the authors purpose that it is necessary to carry out some discussion.

2. EXPLANATION FOR CHANGING OF HOT WATER PRESSURE

Obviously, the well has a surprising result: with the water flowing out gradually, the water level is not reduced or remains unchanged but rises up. The effect is undoubtedly because all of the works are completed by professionals, i.e. there is no problem in the whole process. Then what is the reason for the result?

The author puts forward the idea that the movement mechanism of the groundwater is caused by the density differences from different temperatures. As we know, the water along with the changes of the temperature, the density changes too (Figure 2)\textsuperscript{[2]}. When the temperature is 50 °C, the water density is 988g/L, and at 65 °C, the density of water is reduced to 980.5 g/L.

![The relation curve between the density and temperature of water.](image)

In fact, the heat reservoir may partially accept the drilling-circulating liquid of lower temperature because the pressure of it is higher than that of geothermal water under ground. Therefore the pumping water from geothermal reservoir in the flushing period with lower temperature should have part of the "cold water" until the well flushing process ends. The well flushing process is actually a pumping process while water in the well is moving upward, so the heat reservoir water can continue to releasing to the well at the same time. Then the temperature of well water should be increased gradually although no observation. After the end of well flushing, well water temperature near the ground should be below 50 °C, water table maintained at 8.7m below the ground.

The fresh water(hot water) of reservoir is poured out at the beginning of pumping test, but heat reservoir water upgoing in the well is cooled to below 50 °C because of the shaftwall and nearby (called well surrounding environment) temperature is lower due to the long time drilling process when low temperature liquid circulation leading to long-term effects. However, along with the well pumping test, well surrounding temperature continues to increase and temperature reduction is less and less, so the water temperature gradually increases while water level is rises gradually in the well. After pumped 34h at the pumping capacity of 80m\textsuperscript{3}/h, water temperature rises up to 56°C with the water level rises to the ground below 5.2m. With the continued pumping process, the water level in the well is not decreased but increased by 2.5m. So the pumping test is decided to stop.

After 2min only, water table reaches the ground, and then hot water automatic flowing wellhead(ground) with yield of about 60m\textsuperscript{3}/h. Then water yield increases gradually from 60m\textsuperscript{3}/h increased to 90m\textsuperscript{3}/h of maximum for 8h while water temperature reached to 67°C. Then closing the well over and measuring the water pressure of 0.092Mpa with equivalent of the water column about 9.4m above ground.

The water flow in the well is stopped, as well as the well surrounding environment is still in the process of heating because its temperature is less than the thermal reservoir water temperature, thus the temperature of water in well is decreasing slowly while water pressure reduced gradually. After 9.5h, the observation result is that well water pressure tends to 0(Figure 2).

The water density changes caused by difference of water temperature lead to the change of water table! A simple calculation can be done according to the standards showed in figure 3. Firstly, We need to do a conversion that take no account of other factors, including water as an inviscid incompressible fluid, only calculated in accordance with the specifications given in different temperature density values. Secondly, the wellhead water temperature is 50°C at the beginning of the pumping test and it is 67°C after dewatering test, the water densities were 988g/L and 979.5g/L respectively. Thirdly, assuming the well is vertical with depth of 2148m. Fourth, the initial water is stable or immobile, so that the initial velocity of the water in the well is 0, i.e. \(v=0\). As the
same reason, the well water is still static when the dewatering test is stopped, the water flow rate is 0 too, i.e. \( v_2 = 0 \). Then according to Bernoulli principle:

\[
p_1 + \frac{1}{2} \rho_1 v_1^2 + \rho_1 g h_1 = p_2 + \frac{1}{2} \rho_2 v_2^2 + \rho_2 g h_2
\]

(1)

\( P_1, \rho_1, \nu_1 \) and \( h_1 \) respectively refers to the water pressure, water density, water flow velocity and water level at the beginning of the pumping test \( P_2, \rho_2, \nu_2 \) and \( h_2 \) respectively refers to water pressure, water density, water flow velocity and water level when the dewatering test is stopped. Obviously \( P_1 = P_2 = \text{atmospheric pressure}; \nu_1 = \nu_2 = 0 \). So,

\[
\rho_1 g h_1 = \rho_2 g h_2 \quad \text{or} \quad \rho_1 h_1 = \rho_2 h_2
\]

(2)

According to (2), when the water temperature is 50° C, water column height is 2139.3m, then the water table is 8.7m below ground; in the same way, 67°C water column height is 2157.9m, corresponding water table is 9.86m above ground. They are very close to the actual observation results. If the error is eliminated by observation accuracy and instrument (the observation instrument is poor, the pressure unit in MPa, as shown in Fig. 2), it is considered that the calculation result and the actual observation result are consistent.

In fact, the simple sand tank experiment has confirmed that \(^{[3]}\) penetration rate of hot water is faster than cold water. The most significant feature of hot water is the trend to rise. Therefore, the geothermal energy can change the state of groundwater. The groundwater density will decrease when its temperature increases. In the condition of same pressure, the column height of cold groundwater must be shorter than of hot groundwater result of balance. Geothermal wells can be seen as a vertical pipe, when the pressure at the bottom is fixed, the well tube filled with cold water of larger density corresponding the height of the column is less than the well tube containing a smaller density of the hot water. Therefore, well water table is 8.7m below the ground when well flushing is finished as water in well tube with low temperature; and well water table is 9.4m higher than ground while the dewatering test is finished and well water with higher temperature by 17°C.

3. GEOTHERMAL WATER RECHARGED NEAR SOURCE MODEL IN HILLY AREA

The author thinks about the Jiao dong peninsula in Shandong province where is undulating hills area and many geothermal hot springs are distributed (Figure 4). The hot springs flow mostly perennially. Research of isotope recent years shows that source of hot spring water is from atmospheric precipitation near it, i.e. these hot springs are recharged short range or near the source supply where the topography is hilly area with small topographic changes (Fig. 5). In accordance with general knowledge, it is difficult to guarantee its perennial flow if spring’s recharge source areas were not far because of water flowing needs drive force from the difference pressures.

In accordance with the groundwater flow system theory \(^{[4]}\), groundwater is always supplied in a high area, and discharged in low-lying areas, i.e. the ground elevation of recharge area must be higher than the drainage area.
Figure 4. Shandong peninsula hot springs distribution sketch

- Penglai Wen Shi hot Spring
- Weihai Bao Spring
- Qixia Ai Shan Soup
- Zhaoyuan Tang Dong Spring
- Weihai hot Spring
- MouPing longquan hot Spring
- MouPing yu jia hot Spring
- Wendeng Hong Shui Lan hot Spring
- Wendeng Qi Li hot Spring
- Wendeng Hu Lei hot Spring
- Wendeng Da Ying hot Spring
- Wendeng Wendeng North hot Spring
- Rushan Small hot Spring
- Jimo east hot spring

Figure 5. The eastern hot spring area of geological section in Jimo City

1. The quaternary alluvial and diluvial layer
2. Cretaceous laiyang group Yangjiashuang Fm Siltstone and claystone
3. Yangjiashuang Fm arkose
4. Late yanshanian quartz-monzonite
5. Late yanshanian orthopyre porphyry
6. Bedrock fracture section
7. Drilling position and number
8. Hot spring

Obviously, the fact is inconsistent with the general knowledge or experience, it becomes a basic hydrogeological problem.
In order to solve this problem, the authors put forward the short range recharge model of geothermal water in hilly area (Figure 6). In the water recharge area, the precipitation or surface water penetrates downwards into groundwater under the action of gravity, the groundwater temperature rises when it run down under geothermal gradient. Groundwater continues to flow into the heat source with high temperature, then it leaves the heat source and continues to move to the discharge area.

Therefore the thermal energy can become the driving force for water movement. Thermal energy can change the temperature of the water, can change the density of water and reduce the viscosity of water, so the thermal energy can control the activity of water, of course in the meantime the water chemical properties will also be changed. These changes will be discussed in the future. This paper discusses the changes of water flows caused by the difference density from different temperatures.

4. THE POSSIBILITY OF THE HOT SPRINGS CAN EXPOSE AT HIGHER LANDS WHILE ITS RECHARGE AREA BEING SITUATED LOWER LYING AREAS

From the above discussions we arrival at a conclusion that even if the supply source or recharge area of geothermal water is low-lying its discharge area, it also can form a natural spring. The following is the demonstration for it.

Assuming that there are two sites A and B at the same attitude (Figure 7). There is a heat source with high temperature at 400m underground between A and B, where the rock mass with the temperature above 100°C. If the groundwater flows from A to the rock mass which has lots of fractures and can penetrate water easily, the groundwater in the hot rock mass is heated rapidly and the temperature rises quickly, then it penetrates out from hot rock mass with higher temperature moves up to ground and forms a spring.

![Figure 6 hilly recharge, runoff, heating, geothermal hot spring discharge diagram](image)

![Figure 7 geothermal water cycle diagram of the hot springs can expose at higher lands while the recharge zone being situated lower lying areas](image)
As a result, when the groundwater have a downward movement from recharge area, the groundwater temperature increases constantly with geothermal gradient of 4°C/100m; when the groundwater flows away from heat source and moves up towards to the drainage area, its temperature decreases gradually (figure 7) and with geothermal gradient of 2°C/100-1°C/100m because of the influence of the surrounding geological environment.

As shown in figure 7, the groundwater temperature is 16°C in recharge area and is 32°C near the heat source. After heating by the hot rock mass the groundwater temperature of which flows away from hot source is 96°C; similarly, the groundwater temperature of which near drainage area is 90°C, so the hot spring temperature is 90°C. Calculating its average density and water pressure and changing into water column height, as shown in table 2.

<table>
<thead>
<tr>
<th>Table2 Segmental pressure changes statistics of geothermal water in recharge and discharge area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Items</strong></td>
</tr>
<tr>
<td><strong>Recharge area</strong></td>
</tr>
<tr>
<td>depth of the range (m)</td>
</tr>
<tr>
<td>average Temperature (°C)</td>
</tr>
<tr>
<td>average Density (g/cm³)</td>
</tr>
<tr>
<td>water pressure (pa)</td>
</tr>
<tr>
<td>water column height (m) of 1 g/cm³</td>
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</tr>
</tbody>
</table>

It can be noted that, at the depth of 400m, the pressure formed by the water which is from recharge site and have a low temperature convert into water column height (with density of 1 g/cm³), \( H_{\text{recharge}} = 398.82 \text{m} \); and when the pressure formed by the water which is from discharge site and have a high temperature convert into water column height (with density of 1 g/cm³), \( H_{\text{discharge}} = 385.07 \text{m} \), the difference is 13.75m,

\[
\Delta H = H_{\text{recharge}} - H_{\text{discharge}} = 398.82 \text{m} - 385.07 \text{m} = 13.75 \text{m}
\]

Therefore, when recharge area and the discharge area (spring outcrops) have the same elevation, groundwater temperature recharged from precipitation in recharge area is 16 °C and in discharge area is 90 °C, water head height of hot spring should be above ground 13.75m with the same pressure if the kinetic energy by groundwater flow is ignored.

Further, even the recharge area elevation is lower than the discharge area (spring exposed), as long as the height difference is less than 13.75m, a natural hot spring can also be formed.

Last but not the least, when the hot springs area is of relatively flat terrain, altitude equals everywhere, even if no atmospheric precipitation or surface water supplies, as long as the water level of groundwater in the recharge area is less than 13.75m than ground level of hot spring, groundwater can continuously downwards penetrates to become water source of hot spring and make the natural hot spring flow constantly forever.

5. CONCLUSION

According to the geothermal well pumping test, the conclusion is that density difference caused by temperature lead to geothermal water column height different. The authors use this assumption to put forward the short range recharge model of geothermal water in hilly area. The model explains coexistence mechanism of recharge and discharge areas (hot spring) at the same altitude. So the temperature is an important driving force of groundwater movement. The authors investigate the possibility of recharge in low altitude and discharge in high altitude of geothermal water.
REFERENCE

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