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DISCUSSION ON SOME KEY PROBLEMS ABOUT THE UTILIZATION OF THE UNDERGROUND WATER-SOURCE HEAT PUMP IN URBAN AREA, TIANJIN

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ABSTRACT

More and more people use the underground water source heat pump technology that supply cleaning energy. Due to the remarkable economic benefits and social value of underground water source heat pump technology, there have been twelve heat pump projects in Tianjin. But the technology of underground water source heat pump has some deficiencies in exploiting underground water resources, especially artificial recharge effects, which is the main reason why government decision-maker hesitates to popularize this technology. In this paper, through the analysis about the design of underground water source heat pump system in Hong-Guang Middle School, and other heat pump engineering systems, the author studies some key problems about exploiting underground water resources by underground water source heat pump technology, and brings forward some rational and feasible technology schemes in economy.

INSTRUCTION

The environment pollution and energy crisis have become the two main problems nowadays. People attach more importance to the development of renewable clean energy, due to its benefit of economizing energy and environmental production. As a mature and well-developed technique, the underground water-source heat pump(UWSHP) has been widely used in European and American countries. Although the initial investment is high, the long-run cost will be cut down enormously.

HYDROGEOLOGICAL CHARACTERISTIC

Quaternary Aquifer

Hong-guang high school is a national campus school in Tianjin, especially for Tibetan students. The total area is 35925m^2. The underground water-source heat pump system is designed to supply the air-conditioning and space heating. At first, the geology tectonic characteristics and the nature of Quaternary aquifer will be analyzed in feasibility research.

Hong-guang high school is located at the mid of Cangxian uplift, where the Haihe Fracture and Tianjin Fracture intersect. The depth of the bottom of Cenozoic is -1334m. Quaternary is the main aquifer produced by UWSHP. According to the surrounding bore hole, the characteristics of the aquifers in Quaternary are as follows.

Aquifer group 1: The bottom's depth is 60m. Its upper part is unconfined aquifer and the lower part is the aquifer of coastal deposition. The TDS of salt water is 6-8g/L. The underground water temperature is 16℃. The water level is -1～-2.5m.

Aquifer group 2: The bottom's depth is 230m. Its upper part is the transitional zone of the salt and fresh water. Next is the siltstone between 76～86m and 94～100m. The bottom of the salt water is around -110m. The underlying part is four fresh water aquifers with the depth of 117～122.3m, 147～153m, 173.3～188m and 221～230m. The thickness of the aquifer is 35m, the production rate is 70m^3/h. The water quality is HCO_3-Na, TDS is 0.929g/L. The water temperature is 17℃，the water level is -22m。

Aquifer group 3: the bottom depth is 320m. There are 3 aquifers in it, that the total thickness is 26m, production rate is 50m^3/h. The water quality is HCO_3-Na, TDS is 0.824g/L. The water temperature is 20℃，the water level is -76m。There are already two production wells with the depth of 300m and 265.75m.

Aquifer group 4: the bottom depth is 430m. The main sand zones are located in 306.7～316.2m, 326.7～339.4m, 344.8～358.1m, 363.3～379.4m and 421～430m. The total aquifer's thickness is 48.9m, single well's production rate is 80m^3/h. The water quality is HCO_3-Na, TDS is 0.799g/L. The water temperature is 23℃.

Aquifer group 5: the bottom depth is 466m. The main sand zones are located in 429～442m and 455～466m. The single well's production rate is 90m^3/h. The water quality is HCO_3-Na, TDS is 1.05g/L. The water temperature is 24℃. The water level is -76m.

Table 1 The production rate of the ground water in urban areas of Tianjin(334km^2)[1]

Year	1985	1988	1991	1993	1995	1998	2001	2002	2003
Production Rate ($\times10^4$m^3)	9690	6636	4075	3210	3103	1141	876	754.6	679.7
Intensity ($\times10^4$m^3/ km^2)	29.0	19.9	12.2	9.61	9.0	3.42	2.5	2.2	2.0

The Recoverable Reserves and Production Reliability

The urban areas of Tianjin ia 334km^2. On the condition of depression cone in 1994, the recoverable reserves in urban areas (334km^2) are calculated as follows:

Aquifer group 2: 725.67×10^{4}m^3/a;

Aquifer group 3: 192.3×10^{4}m^3/a；

Aquifer group 4: 233.8×10^{4}m^3/a；

Aquifer group 5: 533.08×10^{4}m^3/a.

The total recoverable reserves of confined water is 1684.85×10^{4}m^3/a.

In 2002, according to the dynamic monitoring data of the groundwater in 2001, the resources were evaluated again. The total recoverable reserves of confined water below the aquifer 2 is 1085×10^{4}m^3/a.

The Hongguang High School is located in the subsidence center of BeiZhan Railway Station. In 1995, the production rate of the group 2 is 1079.73×10^{4}m^3/a, with the water level of -66.4m. The production rate of group 3 is 410×10^{4}m^3/a and the production rate of group 4 is 395×10^{4}m^3/a. The production rate of group 5 and the others below it is 1218.6×10^{4}m^3/a. The total production rate is 3103×10^{4}m^3/a. The deepest water level is -66.4m in Group 2. Since 2000, the annual production rate of the ground water was gradually decreased along with the subsidence controlling (Table 1). Then the water level recovered to -55m in 2003. The ground water system reaches a balanceable condition between recharge and production, and the water level keeps stabilization.

The water level’s recovery means that the production rate is less than the recharge rate in Group 2. So it is feasible to exploit deep ground water in the mode of production and reinjection. If the Hongguang High School use the heat pump as central air-conditioning system, it will produces and reinjects circulating water 858,000 m^3/a, only deplet 38,500 m^3/a water resources. So UWSHP system is dependable to use deep fresh groundwater.

Aquifer’s Selection

Aquifer’s seletion mainly depends on its recoverable reserves, water quality, temperature and environmental effects. The TDS of the fresh water is less than 1000mg/L in Group2, which is suitable for heat pump. Meanwhile, the water level is -22～-23m, which is shallower than the safety line (-30m) of the aquifer’s plastic deformation. So Group 2 is selected as main production zone, and two doublet production and reinjection systems are designed. The aquifers in Group 4 have big flow-rate and good quality, Its water level is deep and easier to inject under the natural state. So Group 4 still has some potential to develop and is selected as secondary production zone. One doublet system is designed in it. The Group 3 is thin and bot easy to use.

DRILLING ENGINEERING

Distance between the production /Reinjection Wells

In a doublet system, when the reinjected water reaches the production well, it will cause the cooling down of the wellhead temperature in production well. So the designing of the distance between the doublet wells is very necessary.

For a doublet system in the same aquifer, if the production rate is equal to the reinjection rate, the formula to calculate the thermal break-through time is[2]：

$$t = \frac{\pi}{3} \cdot \frac{P_a C_a}{P_e C_e} \cdot \frac{D^2 b}{Q} \qquad (1)$$

The shortest distance between the production and reinjection wells is:

$$D = \left(\frac{3P_e C_e \cdot t \cdot Q}{\pi b \cdot P_a C_a}\right)^{1/2} \qquad (2)$$

Where,

D—— the distance between the pro- duction and reinjection wells (m);

C_e—— specific thermal capacity of the fluid (4.18MJ/m^{3}k);

C_a—— specific thermal capacity of the rock in aquifer (0.96MJ/m^{3}k);

P_e—— fluid’s density (1000kg/m^3);

P_a—— rock’s density (2220kg/m^3);

Q ——productive/reinjective rate (m^3/d);

b —— aquifer’s effective thickness (m);

t —— thermal break-through time (d).

It is assumed that the reinjective rate is 900m^3/d, the aquifer’s thickness is 40m. Then during the space heating period in winter, the thermal break-through time is 120 days. The shortest distance between doublet wells is 58.2m.

Even though in winter, the doublets do not operates with the peak load. Meanwhile the hot water is injected when the doublets is used for air-conditioning in summer. So the 50m is a safe distance between doublet wells. If the thermal break-through is happened, the temperature difference is only 1～2℃. It will not make great influences on the doublet system's running.

Borehole Structure

Doublets in Group 2: the well depths are 250m, the diameter is 650mm. The steel pipe of Φ325 mm is installed and the perforated tail pine is the Φ325 mm steel pipe of gravel packing cage type. Top depth of gravel pack is 20m above the perforated pipe. Above -110m, clayey ball is packed to prevent the water infiltration, until the wellhead.

Doublets in Group 4: the well depths are 450m, the diameter is 600mm. The steel pipe of Φ325 mm is installed as the pumping space and the perforated tail pine is the Φ219 mm steel pipe of gravel packing cage type. Top depth of gravel pack is 20m above the perforated pipe. The clayey balls are packed to prevent the water infiltration, until the wellhead.

The length of settling pipe is not less than 5m. And the centralizer and single perforated pipe are installed.

Drilling Techniques

During the drilling, the following points should be carried out:

(1) Cuttings log and drilling hours log, the hole deviation angle is less than 1^o/100m;
(2) The main well logging items are: resistivity, natural potential, diameter, temperature, deviation;
(3) The length of the perforated pipe should be longer than 40m.
(4) The viscosity of mud is less than 14 seconds, the circulating time should be 24 hours before running the tube into well;
(5) After running the tube, the time of circulating outside the tube should be 24 hours. Then the cleaning water is used for circulating when packing the gravel, which is quartzite sand of 1-5mm diameter;
(6) The porosity of the perforated pipe should be more than 25%, the outer twisted space is 1.0mm, the inner one is 1.5mm. The quartzite gravel of 2-4mm diameter is put inside it, the thickness is more than 40mm;
(7) The well is washed by means of piston or vacuum, until the water is clean and the sand density is less than 1/200000.

Prediction of Flow Rate

The reinjective and productive capacity of the perforated pipe can be calculated as:

$$Q_g = \frac{1}{4} \cdot n \cdot \pi \cdot V_g \cdot D_g \cdot L \qquad (3)$$

Where,

Q_g —— injective capacity(m^3/h);

n —— the effective porosity of perforated pipe (50%)；

V_g——permit injective flow speed (0.03m/s);

D_g——outer diameter of perforated pipe;

L ——effective length of perforated pipe (85% of the total length);

It is assumed that the length of perforated pipe is 40m, then the permitting injective flowrate is 90.85m^3/h for D_g=Φ219mm, the permitting injective flowrate is 95.25m^3/h for D_g=Φ325mm.

According to the statistic of 12 UWSHP doublets systems, the aquifer's thickness is more than 35m for the wells drilled into Group 2. The diameter of perforated pipe is 325mm, the flow-rate of single well is 80～90m^3/h, the natural injective rate is 40～50m^3/h. The aquifer's thickness is more than 40m for the wells drilled into Group 4. The diameter of perforated pipe is 219mm, the flow-rate of single well is 80～100m^3/h, the natural injective rate is 60～80m^3/h.

Prediction of Temperature

The isothermal layer's depth is 32m and its temperature is 13.5℃ in Tianjin. Under the isothermal layer, the average thermal gradient is 3.1℃/100m. The aquifer's temperature can be calculated by the following formula:

$$T_g = \left\{ G_g \cdot (D_g - D_0) \right\} + T_0 \qquad (4)$$

Where,

T_g—— the temperature in aquifer (℃);

G_g—— the average thermal gradientof the cap rock (3.1℃/100m);

D_g—— the aquifer's depth (m);

D_0—— the isothermal layer's depth (32 m);

T_0—— the isothermal layer's temperature (3.5℃).

The temperature at the top of Group2 (110m) is 15.6℃, and at its bottom(230m) is 19.1℃. The average temperature is 17～18℃ at the wellhead, due to the borehole effects.

The temperature at the top of Group4 (360m) is 21.7℃, and at its bottom(430m) is 24.5℃. The average temperature is 23℃ at the wellhead, due to the borehole effects.

Table2 The Water Quality of the Aquifers in Group Ⅱ and Group Ⅳ

Aquifer	No.	Mineralization (mg/L)	Main ion's contents(mg/L)						hardness	alkalinity	PH	TDS (mg/L)
			K+Na	Ca	Mg	Cl	SO_4	HCO_3	Deutsche Degree			
Ⅱ	1	930	213	80	17	72	85	461	6.5	21	7.8	640.8
	2	640	138	26	14	45	43	371	6.67	17.1	8.1	557.6
□	3	860	218	96	1.7	93	30	361	1.08	18.1	8.4	562

Table 3 The Stable Index of Aquifer 2 and Aquifer 4

Aquifer	A	B	C	D	PHs	PH	S
Ⅱ	0.20	2.16	2.05	2.57	7.44	7.8	7.08
Ⅳ	0.19	2.02	1.26	2.52	8.13	8.4	7.86

WATER QUALITY ANALYSIS

The Water Quality of the Aquifers in Group2 and Group 4 are listed in Table 2.

Stale Index of the Groundwater

The stale index of the groundwater canbe calculated as:

$$S = 2PHs - PH \qquad (5)$$

Where,

PH ——measured PH;

PHs ——PH with the saturated$CaCO_3$.

The water stability is decided by the value of Stable Index S.

S <3.7, serious scaling;

3.7< S < 6.0, scaling;

S ≈6.0, stable;

S >7.5, serious corrosion;

6.0< S <7.5 corrosion.

$$PHs = 9.7 + A + B - C - D \qquad (6)$$

Where,

A —— index of total dissolved solid;

B —— index of temperature;

C —— index of calcium hardness;

D —— index of alkalinity.

Then the calculated results are listed in Table 3.

Both of the stable index of aquifer 2 and aquifer 4 are more than 7. So it will not cause the scaling during the reinjection. Meanwhile, it exits the possibility of the dissolving and corrosion for the calcite and feldspar in aquiferi and filtration amterial.

Chloride corrosion

When the alloy steel plate heat exchanger is uses in normal groundwater heat pump, the chloride concentration should be less than 200mg/L. The chloride concentration is 26～80 mg/L in aquifer 2 and 96mg/L in aquifer 4. Both of them are meet the demands of heat pump.

Calcium sulphate scaling

When the products of contents for Ca^{2+} and SO_4^{2-} are less than 1.5×10^5, it will not calcium sulphate scaling. The products are 6800 and 2880 in aquifer2 and aquifer 4, so the calcium sulphate scaling will not happened.

Reinjection water quality

The reinjection is a key problem in the technology of groundwater source heat pump. According to the analysis about its utilization in eastern area in China, the decrease of the reinjection rate will happen after the reinjection well running for several months or 2 ～ 3 years. Sometime the reinjection wells were abandoned. The main reason is the chemical and bacteria plugging. So it is necessary to make some demands on reinjective water quality.

Normally, the original water from the productive wells are reinjected in ground water source heat pump system. Its chemical contens will not changed in a close system. But it will suspend or dissolve some impurity. So the coarse (50μ) and fine (50μ) filtration systems are needed.

After the filtration, the reinjection water should be analyzed according the criterion SY/T5329-94. Then adopt the necessary water disposal measures.

The reinjection well head should be vacuum, and reinjection should be in the pump pipe. When the reinjection rate decreases or water level continously rises, it can be inspected that if the filtration system is plugged through the intermittent pumping.

For physical plugging, it can be solved by short-time pumping. During the pumping, the water will become clear, the water level will go to stable. It needs to

check the reinjective and productive water quality in time.
The pumping space should be spout and coat some anticorrosive material, to prevent the well pipe's corrosion and the other water's mixing. If some other water mixed in, immediately adding some medicament (such as bleaching powder, limewater) is necessary, to increase th PH value and restrain the iron bacteria's growth.

CONCLUSION

The groundwater source heatpump is already a mature technology in other European countries. In China, it starts to apply widely in some city, such as Beijing. m
But due to some natural geological conditions, such as fine grains in aquifer, some difficulties still exists in Tianjin, for application of groundwater source heatpump. However, it still has a great future, after the strict designing of drilling technics, water quality, production rate, etc.

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