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ARTICLE

STUDY ON THE CALCULATION OF HEAT RESOURCE RESERVES

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ABSTRACT

The evaluation results provide a scientific basis for the further development of the geothermal field around the lake. The results show that the geothermal field calculated by single well pumping test method is known. It can meet the research requirements of d-grade reserves of geothermal field, and can be used as the basis for planning the development of local geothermal field. The ground temperature is relatively high, which can be used as the reserves of Grade C geothermal field. Basically, the chemical composition and special mineral composition of underground hot water have been identified, and a hot water well (exploration and mining combined well) has been built, which provides a scientific basis for further exploration, evaluation and development of Huchi surrounding geothermal field.

KEYWORDS

Geothermal, huchi surrounding geothermal field, evaluation

1. OVERVIEW OF ENVIRONMENTAL GEOLOGICAL CONDITIONS

Physical Geography

Huchi surrounding geothermal field is located in the tidal flat of Jinxingmen Port on the southeast side of Cuiheng Village, Nancuo Town, Zhongshan City. The central geographic coordinates are E 113° 31' 31" - 113° 34' 30", N 22° 24' 22" - 22° 26' 48", with a total area of 23 km^2, of which the sea area is 16 km^2 and the land area is 7 km^2.

1.2 Meteorology and Hydrology

The geothermal field is located in the low latitude area south of the Tropic of Cancer, and belongs to the subtropical marine monsoon climate, with long sunshine hours, large temperature difference between day and night, warm and humid, abundant rainfall, concentrated rainfall, and less frost in winter [1].

1.3 Topography

Geothermal fields are composed of land and sea. The land part is mainly composed of coastal plains and denuded mounds. The coastal plain has flat and open terrain, high in the west and low in the east, slightly inclined to the sea, with an inclination angle < 6°, and the ground elevation is 6-19 m; The vegetation of the denuded mounds is developed, the rocks are mostly covered by weathered residual soil, and the bedrock is only partially exposed [2]. The sea area is mainly tidal flats, with a water depth of 2 to 5 m at high tide and 0 to 3 m at low tide. During each month, the tidal flats are exposed at low tide, and a large number of hot springs can be seen. At present, most of the tidal flats in the area have been reclaimed for aquaculture field [3,4].

1.4 Strata and Magmatic Rocks

The strata distributed in the geothermal field are mainly Quaternary, which are divided into artificial accumulation layer, Denglongsha Formation, Wanqingsha Formation, Triangle Formation and granite weathered residual layer from top to bottom. The magmatic rocks are intrusive granites of the third stage of Yanshan (γ5 2(3)), which are widely distributed in the area and are mostly buried underground. The lithology is coarse-grained and medium-grained biotite granites, rock compact hard, coarse grain structure, massive structure.

1.5 Geological Structure

The geothermal field is located in the southern part of the Pearl River Delta, and the regional structure is located in the southwest section of the Heyuan deep fault zone. The regional crust has experienced multiple complex tectonic movements (Caledonian-Indosinian and Yanshanian tectonic movements) and different periods of magmatic activity (Mainly due to the strong magmatic activity in the Yanshan period), forming a regional fault tectonic framework that cuts each other and is intricate. According to the comprehensive analysis of geological and hydrogeological data, the regional geological structure is dominated by fault structures that cut each other. There are 12 regional faults in different directions, and a series of secondary faults are generated. The regional geological structure is relatively complex. The outcrop point of the hot spring is located in the secondary fault, which is a secondary fault inferred from the geothermal isotherm map and geothermal drilling data, and spreads in the east-west direction.

1.6 Hydrogeological Features

1.6.1 Overview of Groundwater Occurrence

The geothermal field is located on the west side of the Pearl River Estuary, surrounded by mountains and seas. The overall terrain is inclined from west to east. It has a subtropical marine climate with abundant rainfall. In addition, the crust in the region has experienced multiple complex tectonic movements, especially in the Yanshan period. The strong fault block movement and multi-period magmatic activities have resulted in the development of faults and broken rocks in the area, providing favorable geological environment conditions for the recharge, migration and occurrence of groundwater. Loose rock pore water is mainly distributed in the coastal plain area in the west of the geothermal field. Because the geothermal field is an offshore area, the terrain is low, the groundwater level is shallow and is affected by the tide, the groundwater circulation and alternation is slow, and the loose rock pore water often has seawater retention. Saltwater areas are formed.

1.6.2 Groundwater Types and Water-Rich Division

According to the occurrence conditions, hydraulic properties and hydraulic characteristics of groundwater in the geothermal field, the groundwater in the area is divided into two categories: loose rock pore water and bedrock fissure water. Among them, the loose rock pore water includes fresh water and salt water, and the bedrock fissure water is only the massive rock fissure water.

1.6.3 Water Richness and Water Quality Characteristics of Groundwater

1) Loose rock pore water aquifer

(1) Freshwater-poor area: distributed in the western part of the geothermal field, the lithology of the aquifer is mainly silty sand and silt, thick 2.65 m to 10.67 m. The chemical type of water is HCO_3—Na or HCO_3·Cl—Na·Ca type, the total soluble solid is 120-570 mg/L, and the pH value is 6.4 to 7.5.

(2) Salt water-poor area: distributed in a belt along the coastline, the main lithology of the aquifer is silty silty sand, clay-bearing gravel sand, medium-coarse sand, thick 5.27 to 48.53 m. The chemical type of water is Cl—Na type, the total soluble solid is 1 200-3 400 mg/L, and the pH value is 6.9 to 7.5.

2) Bedrock fissure water

The bedrock fissure water in the local hot field is all massive rock fissure water, and the amount of water is medium-poor, which is briefly described as follows.

Medium water volume area: distributed in the west of the geothermal field, the aquifer lithology is mainly biotite granite and fine-grained granite, with developed fissures and medium water richness. The chemical type of water is HCO_3—Na·Ca type, the total soluble solids are 45-258 mg/L, and the pH value is 6.3 to 7.1.

Water-poor area: distributed in the northwest corner of the geothermal field, the lithology of the aquifer is mainly biotite granite, fine-grained granite, monzogranite, etc. The chemical type of water is HCO_3·Cl-Na type, soluble total solids 105. 2 to 756.1 mg/L, pH value 6.5 to 7.2.

2. GEOLOGICAL CHARACTERISTICS OF GEOTHERMAL FIELDS

2.1 Geological Characteristics of Thermal Storage and its Caprock

The local thermal field is located in the coastal tidal flat, and the surrounding terrain is relatively high. There are many faults passing through the geothermal field, which provides good supply and storage conditions for the formation of underground hot water. The local thermal field is a belt-shaped thermal storage, the upper part of which is covered with a good caprock.

2.1.1 Thermal Reservoir Caprock Characteristics

The thermal reservoir caprock is mainly composed of silt deposited by Holocene marine facies and cohesive soil of Yanshanian granite weathering residual, etc., with good thermal insulation.

2.1.2 Thermal Reservoir Characteristics

The thermal reservoir is mainly composed of the Yanshanian granite weathered fracture zone and the fractured zone, and it is a banded thermal reservoir. Along the fault structure, the core is broken, joints and fissures are developed, thermal alteration, thermal dissolution, thermal precipitation are obvious. And the joints are filled with chlorite, pyrophyllite, and fluorite. These void channels provide good storage and transport conditions for the formation of underground hot water.

2.2 Characteristics of Geothermal Field

Huchi surrounding geothermal field is located in the tidal flat of Jinxingmen Port, which is submerged by shallow water all the year round. During the monthly synodic period, groups of hot springs can be seen exposing the tidal flat when the seawater ebbs. The exposed range of hot springs is about 0.262 km^2, the highest water temperature is 102°C, generally 40°C to 60°C, and a lot of hot fog emerges. At present, in the geothermal anomaly area, embankments have been built to surround fish, and the water depth is more than 3 m, so it is difficult to see obvious springs. The hot springs are still clearly visible only after the water is released at low tide.

2.3 Recharge, Runoff and Discharge Characteristics of Geothermal Fields

Atmospheric rainfall infiltration recharge is the main source of recharge of underground hot water in local thermal fields. The geothermal field is located in the shallow tidal flat of Jinxingmen Port, surrounded by relatively high hills in the west and southwest, with well-developed vegetation in the hills and mountains. The lithology of the topsoil is mainly granite weathered residual soil, which is conducive to the infiltration of atmospheric rainfall. The bedrock has undergone multiple complex tectonic and magmatic activities, broken rocks and developed fissures. It is a good channel for groundwater recharge and runoff.

Based on the analysis of the terrain, geomorphology and geological environment, the hilly and mountainous areas with relatively high topography in the west and south of the Huchi surrounding geothermal field are the main recharge areas for the local hot field. After the atmospheric rainfall infiltrates through the pores of the residual soil layer in the recharge area, shallow groundwater is formed, and some of the shallow water is exuded to replenish rivers and streams. The other part continues to supply laterally along water conduction channels such as rock and stone wind fracture zones and fault fracture zones, and then flows to deep underground to obtain heat energy, forming underground hot water. Under the action of thermal force and head pressure, it migrates upward along the channel of water conduction fracture zone and fault fracture zone, and finally drains out to sea in the form of spontaneous flow or artificial mining.

Because the groundwater dissolves the soluble material of the surrounding rocks in the process of replenishing and path flow, the local thermal fluid contains some special mineral components which are different from ordinary groundwater.

3. CALCULATION AND EVALUATION OF GEOTHERMAL RESERVES

The calculation and evaluation of geothermal reserves is mainly the calculation and evaluation of the recoverable reserves of geothermal fluid resources. The calculation and evaluation of the reserves of local hot fields is based on the pumping test.

3.1 Pumping Test

As the local hot field is located in the shallow beach with a depth of 3-4 m, the construction needs auxiliary tools such as tugboats. The water temperature at the orifice is as high as 99°C (sometimes up to 102°C). When the well is completed, the accumulated hot water at high temperature and pressure for years gushes out with a maximum height of 8. 2 m, which brings great difficulties to drilling construction, pumping test and dynamic monitoring. The pumping test results of geothermal fields are determined according to the head height and self-flow of drilling artesian flow, as shown in Table 1 and Figure 1 and Figure 2.

3.2. Calculation of Geothermal Resources Reserves

The local hot field is a zonal heat reservoir, and the distribution of geothermal fluid is directly controlled by the fault structure. The amount of water inflow from boreholes mainly depends on the fault nature, fracture development and filling degree. Therefore, it is not suitable to use uniform well distribution method to calculate the recoverable reserves of thermal resources in local hot fields. Instead, it can be calculated and determined according to the pumping test data of single well, borehole (well) self-flow data and dynamic observation data of underground hot water based on the actual situation of local hot fields.

3.2.1 Single Well Pumping Test to Determine Recoverable Reserves

The pumping test of the geothermal field is shown in Table 1, Figure 1 and Figure 2 as described in Section I. In order to determine the recoverable reserves of tube-wells with uniform depth reduction and caliber, the corresponding formula is used to calculate according to the pumping test data and curve type. According to the pumping test data, the drawn Q = f(x) curve and the discriminant of curve types show that the curve types are all exponential. Therefore, the water inflow of tube-wells in local hot fields can be calculated according to the exponential equation of the empirical formula for the water inflow of tube-wells.

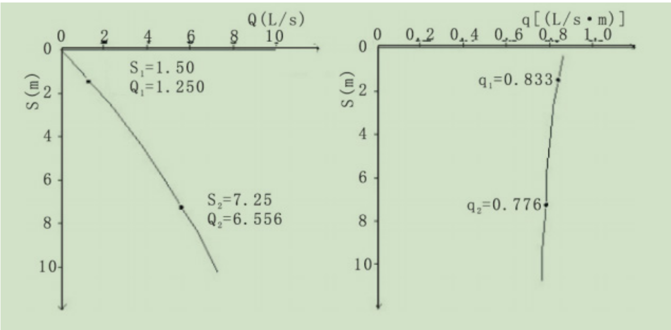

Figure 1: Pumping curve of hot well R1

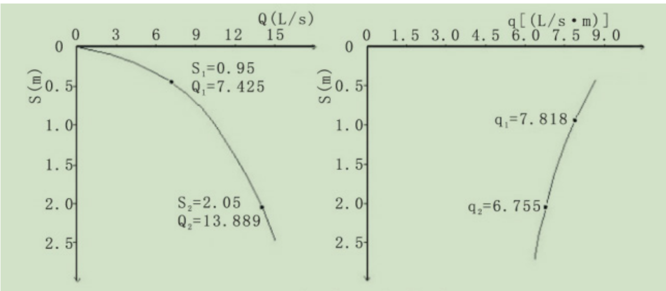

Figure 2: Pumping curve of hot well R2

1) Calculation formula

Discriminant of curve type: m = $(\lg S_2-\lg S_1) / (\lg Q_2-\lg Q_1)$

The empirical formula for calculating borehole (well) water inflow:

Exponential Q is equal to n times S_1 over m

The empirical coefficient is lgn = $\lg Q_1$-1m $\lg S_1$

The calculation formula of pipe diameter water flow is $\eta = (1 + r/r_1) /2$

In the formula, Q, Q_1 and Q_2 are the water inflow (m^3 /d) of the first and second drop routes of the tube well design and pumping test, respectively; S, S_1 and S_2 are the depth reduction (m) of the first and second drop path of tube well design and pumping test, respectively; n is the number of tested lines; m is the relationship number of depth-water quantity; η is the conversion factor of pipe diameter and water volume; r and r_1 are the designed inner diameter of mining well and the actual inner diameter of pumping well (mm) respectively.

2) Determination of calculation parameters

Design depth reduction S: According to the actual situation of local hot fields, the design depth reduction of extraction Wells is 1 of the actual maximum depth reduction. 75 times, each set at 12.7 m (well R1), 3.6 m (well R2); design well diameter (r): The inner diameter (straight diameter) of the pumping well is set as 200 mm.

3) Calculation results

According to the above calculation formula and relevant parameters, the recoverable reserves of local hot fields were determined to be 2 558 m^3 /d by pumping test method (Table 2).

3.2.2 Drilling (Well) Self-Flow to Determine Recoverable Reserves

Two hot water Wells were constructed in December 2002 (dry season). The steady self-flow rate of the first well (well R1) was 5. 56 L /s (480 m^3 /d), the second well (No. R2 well) after completion of the stable self-flow rate of 13. 89 L /s (i.e., 1 200 m^3 /d). According to the observation, after the completion of well R2, the self-flow rate of well R1 decreased significantly, which was two thirds of the original self-flow rate, and was 320 m^3 /d by measurement. That is, when the stable self-flow rate of well R2 was 1 200 m^3 /d, the stable self-flow rate of well R1 was 320 m^3 /d. At the same time, the dynamic monitoring of the hot Wells after well completion for a period of one year (January to December) shows that the self-flow, water temperature and water quality of the two hot wells are basically stable (Table 3). Therefore, it is guaranteed that the stable self-flow rate of 1200 + 320 = 1 520 m^3 /d after the completion of two hot water Wells in dry season is taken as the recoverable reserves of the local hot field.

2.3 Calculation of Geothermal Resource Reserves

According to the actual situation of the geothermal field, the calculation of the recoverable reserves of geothermal resources has adopted two methods: the pumping test method and the borehole (well) self-flow statistical method. Among them, the recoverable reserves (1520 m^3/d in total) determined by the self-flow statistical method of the boreholes (wells) are the stable self-flow of the two hot water wells during the dry season. It is relatively stable, and its value has a high degree of geological reliability. It is highly guaranteed as the recoverable reserves of the local thermal field, and can be used as the C-level reserves of the local thermal field; The recoverable reserves of geothermal resources calculated by pumping test method are calculated and determined based on the actual pumping test results of local hot fields. the pumping time is 80-178 h, and the stabilization time is 72-168 h. After a year of dynamic monitoring, the water quality, water quantity and water temperature are relatively stable. The selected calculation parameters are in line with the actual situation of the local thermal field, the calculation method is reasonable, and the calculation result is reliable. The value (2558 m^3/d) meets the exploration requirements of the D-level reserves in the geothermal field, which can be used as the basis for the development planning of the local thermal field.

According to the drill holes, the buried depth of thermal storage in local thermal fields is mostly 13-30 m, and the depth of completion of wells in geothermal fields is less than 100 m, which is the most economical depth of formation of hot water wells; the unit water inflow volume of hot water wells in geothermal fields is greater than 50 m^3 /(d·m), which is the most suitable mining area for geothermal resources.

To sum up, the local thermal field is the most economically exploitable geothermal field. The C + D grade reserves of geothermal resources are 2 558 m^3/d, of which the C grade reserves are 1 520 m^3 /d and the D grade reserves are 1 038 m^3 /d.

4. DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES AND EVALUATION OF ENVIRONMENTAL PROTECTION

4. 1 Evaluation of The Development and Utilization of Geothermal Resources

4.1.1 Aspect of Healthcare

Hot mineral water often contains some trace elements and mineral components that are beneficial to human health. It can be absorbed and utilized by the human body through showering and other methods, and has a certain medical and health care effect on the human body. The groundwater temperature and mineral content of the Huchi surrounding geothermal field are relatively high, and the salinity is greater than 1 000

Table 1: Pumping (artesian flow) test results of No. R1 and R2 wells

Number	Test section depth	Pumping date	Pumping time	Stable schedule	Still water depth	Water level drawdown		Water inflow	Water inflow per unit	Water temperature	Well completion depth
						Order	Drawdown				
R1	59.00-77.96	03.2.8-2.18	80:00	72:00	+8.20	1	1.50	1.250	0.833	97.0	77.96
			176:00	168:00		2	7.25	5.556	0.776	98.0	
R2	34.56-83.00	03.2.19-3.1	82:00	72:00	+2.68	1	0.95	7.425	7.818	99.0	85.55

Table 2: List of recoverable reserves calculated by pumping test method

Calculation parameters									Recoverable reserves
Number	S_1	S_2	S	Q_1	Q_2	R_1	η	m	n	Q
R1	1.50	7.25	12.7	108.0	480.0	243	0.912	1.056	73.57	745
R1	0.95	2.05	3.6	641.5	1200.0	220	0.955	1.228	668.9	1813
All										2558

Table 3: List of dynamic monitoring of No. R1 and R2 hot water wells

Number 1		Month											
		2	3	4	5	6	7	8	9	10	11	12	
R1	L/s	3.70	3.65	3.59	3.70	3.73	3.70	3.76	3.82	3.94	3.88	3.82	3.73
	m^3/d	320	315	310	320	322	320	325	330	340	335	330	322
	℃	99	98	100	99	98	98	98	99	99	99	98	99
R2	L/s	13.9	13.7	13.3	13.9	14.1	14.5	14.5	14.8	15.3	15.1	14.5	14.0
	m^3/d	1200	1180	1150	1200	1220	1250	1250	1280	1320	1300	1250	1210
	℃	98	99	97	97	98	97	97	98	97	98	98	98

mg/L. There are many indicators that meet the water quality standards of medical hot mineral water. It has a better health care effect on the human body. However, its medical effect must be determined through clinical trials.

In addition, there are a lot of mineral-rich mud in the geothermal field, which is an excellent mineral mud. The mineral mud soaked in hot mineral water is applied to the body or the affected area, which has the effect of fitness and healing. Therefore, the local hot field can also be developed as a new hot spring physiotherapy project-mud bath, which is popular in the world today.

4.1.2 Aspect of Agricultural Utilization

Zhongshan City, where the geothermal field is located, is known as the “Guangdong Granary”. In addition to rice and wheat and other food crops, it also grows sugarcane, sericulture, fruits, vegetables, flowers, etc., and can use underground hot water resources to develop “three high” agriculture. For example, the use of low-temperature hot water to promote germination, raise seedlings, cultivate excellent varieties, and cultivate potted fruits, flowers and plants in greenhouses can not only shorten the growth cycle, but also increase crop yield.

Using underground hot water to accelerate germination can save time, money, labor and environmental protection. Geothermal germination can shorten the germination time by more than half, and save fuel and labor, simple operation, convenient management. The accelerated seeds grew well after sowing. In addition, underground hot water can also be used for crop seedling in winter.

4.1.3 Aspect of Aquaculture

The geothermal field is located in the Pearl River Delta region, a “land of fish and rice”, with a developed aquaculture industry and a long history. The African crucian carp is cultured in underground hot water, which can make it safe for overwintering, which is used in many parts of the country. In addition, the use of underground hot water to breed turtles has the advantages of short cycle and high yield, and the economic benefits are very significant. At present, the Huchi surrounding geothermal field has been reclaimed into an aquaculture farm, and a variety of high-quality fish (such as African crucian carp, pomfret, soft-shelled turtle, shrimp and crab) have been cultivated. In order to make aquaculture farms exert better economic benefits, it is necessary to rationally develop and utilize Huchi surrounding geothermal fields.

4.1.4 Aspect of The Development of Tourism

Huchi surrounding geothermal field is located in Jinxing Port at the junction of Zhongshan and Zhuhai. It is near the Pearl River in the east, facing Shenzhen and Hong Kong across the sea, adjacent to Zhuhai and Macao in the south, and bordering on Panyu and Shunde in the north, which leads directly to Guangzhou. Beijing-zhuhai Expressway passes through the west side of the geothermal field, making the traffic very convenient. There are blue sky and blue sea, beautiful environment and superior geographical location. There are many scenic spots and natural landscapes around. If these places of interest, natural landscapes and local hot fields are integrated and developed as tourism resources of Zhongshan City, it will surely attract a large number of tourists from home and abroad and have a positive impact on the tourism industry of Zhongshan City.

4.2 Environmental Impact Assessment of Geothermal Resources Development and Utilization

From the above analysis, it can be known that the local hot field has a favorable geographical location and a wide range of hot mineral water should be used, which is in line with the advantages of environmental protection, sanitation and energy saving, and has great mining value. As long as it is rationally developed and utilized, it will generally have no adverse impact on the surrounding environment. But if the mining is not reasonable, it may cause seawater intrusion. In addition, the direct discharge of geothermal fluid will also have some effects on the surrounding environment.

4.2.1 Seawater Intrusion

The local hot field has been submerged in seawater for many years, and the thermal reservoir is mainly composed of Yanshan Phase III granite weathering fissure zone and fault fracture zone. Its thickness is large and the groundwater supply is sufficient. As long as the mining is reasonable, there will generally not be large-scale seawater intrusion. However, geothermal resources, like all groundwater resources, are renewable resources, but their supply is limited after all. If they are exploited indiscriminately, groundwater hot water resources will be depleted, and the groundwater level will drop significantly, causing negative pressure on the groundwater level in the geothermal field (the part where the groundwater level is lower than 0m) and causing large-scale seawater intrusion. Therefore, when exploiting local thermal resources, it is necessary to carry out a developmental pumping test first, and use the test parameters to obtain reasonable mining drawdown, single well water inflow and the distance between mining wells, and strictly control its mining volume to avoid large-scale seawater intrusion in the geothermal mining area due to unreasonable mining and excessive mining.

4.2.2 The Impact of Geothermal Fluid Emissions on The Environment

The results of water sample analysis show that although the geothermal fluid in the region contains some harmful elements or components, such as lead, fluorine, etc., the content is low and generally does not cause pollution to the surrounding environment. However, the direct discharge of waste geothermal fluid may cause thermal pollution to the surrounding environment. Therefore, in the process of developing geothermal fields, the discharged waste geothermal fluid should be cooled to avoid pollution to the surrounding environment.

5. CONCLUSION

The comprehensive geothermal geological survey of the Huchi surrounding geothermal field in Zhongshan City has basically found out the scope of geothermal anomalies, the buried distribution characteristics of thermal reservoirs and the main characteristics of heat-control structures. Basically, the chemical composition and special mineral composition of underground hot water have been identified, and a hot water well (exploration and mining combined well) has been built, which provides a scientific basis for further exploration, evaluation and development of Huchi surrounding geothermal field.

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