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The Technology of Aquifer Thermal Energy Storage and Its Application to Marine Products Breeding

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ABSTRACT

The technology of aquifer thermal energy storage (ATES) is a new method of energy conservation using a two-well system, which utilizes the aquifers for the temporary storage of low-grade thermal energy during the summer season and the winter season respectively. Then the water is withdrawn and the seasonal thermal energy is used to meet the demands of space heating and air conditioning accordingly. Because of its effective savings in the consumption of fossil fuel resources, the technology is becoming more widespread. . The ATES technology has been successfully used in Marine Products Incorporated Company's new building extensions in order to maximise the use of stored heating and cooling energy.. Its application to the project will provide valuable data, which will allow for the design of an economic solution.

1. INTRODUCTION

With the rapid development of the Chinese national economy and continuous improvement of living standards, the demand for energy has risen in daily life, industry and business. Nowadays, energy is in serious shortage, but the traditional methods of energy usage cause great environmental pollution and energy waste. Air conditioning is widely used to bring coolness to people, but at the same time, it releases heat energy to the air, which results in the "heat island effect", makes the temperature rise and brings serious thermal pollution to the city. In addition, if vast low-grade thermal energy resources such as industrial waste water, municipal sewage, lake and city tail water are not utilized with new technology, then left unused or released directly, the energy will not only create environmental thermal pollution, but also result in extreme resource waste. Some data indicate that if the waste heat which is released from 1,000 seats of 50,000m^2 buildings is fully utilized, it could displace a large or middle-scale hydroelectric station.

The deep aquifer thermal energy storage technology offers a technical solution for attaining such a goal to transform the energy utilization method from the "large-amount exploitation, low-efficiency utilization and large-amount discharge" to "low-amount exploitation, high-efficiency utilization and low-amount discharge". The application of such technology is not only to reduce the heat (cold) pollution to the air, but also to promote the utilization efficiency of energy. As such , this technology is of very important social value and economic value to protect the environment and save energy. At the same time, the technology can balance the yield of underground thermal water and the recharging quantity to maintain the pressure in the aquifer effectively and to avoid the differential surface settlement due to the extraction of underground water.

This approach permits the use of low grade renewable energy to achieve the goals of energy saving, , environmental protection, cost reduction, and sustainable utilization of resources.

2. DEEP AQUIFER THERMAL ENERGY STORAGE TECHNOLOGY

The basic principle of deep aquifer thermal energy storage technology is to fully utilize the storage capacity of an aquifer to meet the objective of "recharging in summer and using in winter" and "using in summer and recharging in winter". The basic thoughts are: build two geothermal wells; one for recharging the hot water (hot water well), and the other for recharging cold water (cold water well). In winter, pump the water from the hot water well, and recharge the water back into the cold water well after the hot water has been circulated in the pipelines for surface buildings and the water temperature has dropped to a certain point; and use the recharged cold water and the strata aquifer as the cold energy storage medium which shall be used as the cooling resource in summer. Similarly, pump the cold water from the cold water well, and recharge the water back into the hot water well after the cold water has been circulated in the pipelines for surface buildings and the water temperature has risen to a certain point, which shall be used as the heat resources for heat supply in winter.

The effectiveness of deep aquifer thermal energy storage technology is closely related to the energy storage strata, energy storage well and other parameters. . The energy storage efficiency of strata mainly depends on the arrangement of the energy storage wells, at the same time, the service life of deep aquifer thermal energy storage well is closely related to the water quality of recharged water. Thus it can be seen that the effectiveness of deep aquifer thermal energy storage technology is closely related to many factors.

2.1 Energy storage strata and well

2.1.1 Selection of energy storage strata

The deep aquifer thermal energy storage technology uses the tube-well recharging and exploitation to store the cold water or hot water in the underground aquifer. Accordingly, the selected aquifer and the hydrogeological conditions shall be favorable to the energy storage requirements. Also the water temperature and quality of the water resources recharged back into the aquifer must not create any harmful environmental geological problems.

In selecting the energy storage strata, the hydrogeological conditions of the energy storage aquifer shall meet the following requirements: (1) the aquifer shall be homogeneous and of certain permeability, with slow flow rate of underground water; (2) the aquifer shall be thick and widely distributed; (3) there is no abnormality in the geothermal gradient, with little variation in temperature; (4) the upper and lower impermeable stratum of the energy storage aquifer is distributed evenly, with good water-resisting and insulating properties; (5) the underground water in the aquifer must not contain any harmful gas and chemicals which can corrode the well tube filter; (6) The energy storage process in the aquifer will not induce any environmental geological problems, such as regional heat pollution and surface settlement.

2.1.2 Layout of energy storage wells

The energy storage well has a similar construction to the ordinary pumped well, which consists of the casing pipe, well tube filter, detritus tube, sand filling layer and seal coat. The arrangement of energy storage wells shall be designed according to the energy storage purposes and the local hydrogeological conditions. It is advisable to design the overall scheme to avoid the well temperature disturbance, water quality pollution and other unfavorable consequences. Before drawing up the layout scheme of energy storage wells, it is required to understand or find out the following environmental conditions: (1) the local hydrogeological conditions, including the burial depth, thickness, lithology, permeability of aquifer, water-abundance flow direction, feeding and supply resources, natural recharge capacity, table of underground water, water chemical composition and dynamic water temperature variation, and so on, (2) the dynamic situations of the underground water table, development situation of local underground water table, (3) recharging and exploitation situation of recharging and exploitation wells in various aquifer, (4) to measure the related hydrogeological parameters that are closely related to the tube well recharging, including the unit water output, unit recharging amount, underground water table, water temperature, background parameters for water quality, (5) energy storage water resource situations, which includes the surface water and other water resources, (6) the energy storage well shall be free from the areas where there are surface or underground sewage and waste hot water storage project to avoid contamination to the underground water, (7) for the section where only one simple energy storage well (a well recharged in winter and utilized in summer or a well recharged in summer or utilized in winter) is to be set, only the conditions that are good for the recharging, exploitation and utilization shall be taken into account for the design of the well layout. For the sections with two wells or a group of wells to store the cold energy or heat energy, the well spacing interval shall be calculated to avoid mutual disturbances between the hot water and cold water during the long-term recharging and exploitation process.

2.2 Water quality requirement and pretreatment technology for recharging water resources

In order to prevent underground water pollution and protect the underground water resources, it is required to set requirements on the quality of recharging water resources. In determining the water quality standards of recharging water resources, it is advisable to pay attention to the following three principles: the quality of the energy storage water resources shall be slightly higher than the original underground water. It needs to meet the standard of drinking water; the energy storage process cannot deteriorate or pollute the underground water quality; the energy storage water resource does not contain the special ions or gases that will corrode well casings and well tube filters.

The underground water, as the recharging water resource, often contains high quantities of ferrous ions; if such water is directly used in recharging, it may result in the blockage of the energy storage well. Therefore, iron removal treatment must be done to the water prior to recharging. The treatment method is very simple. Sprinkling the recharging water resources in the air or making the recharging water pass through manganese sand not only depresses the ferrous content but also reduces the turbidity.

3. APPLICATION OF DEEP AQUIFER THERMAL ENERGY STORAGE TECHNOLOGY TO SEA-WATER AQUICULTURE

3.1 Overview of Project

Tianjin Haifazhanpin Co. Ltd. is located in Tanggu District, Tianjin City, close to the Bohai Gulf, with a covered area of 50 000 m^2. It is in the North China Subsidence Zone of secondary building unit and Banqiao Topographic Depression of Binhai Area. This area belongs to the Binhai Plain deposited in Cenozoic era. The strata from the Achaean group to Cenozoic group were all developed in this area.

Table 1 indicates the strata of this area from the lower upward.

This company works on industrialized sea culture. This company mainly breeds the *paralichthys oliuaceus*, as well as *epinephelus drummondhayi* and the *flatfish*. These are all high-grade economic fishes, which are characterized by high nutritive value, fast growth rate and strong fertility, but with poor adaptability and strict requirements on the water quality, water temperature and other aspects.

According to the local meteorological data, the time when the natural water temperature of the water body in Bohai Gulf is lower than 10°C is about 5 months; the annual lowest temperature in Bohai Gulf is -1°C, and the highest temperature is over 31°C (such a high temperature will last one month in each year). Therefore, in order to attain the industrialized breeding goal to make the *paralichthys oliuaceus, epinephelus drummondhayi,* and *flatfish* output high and stable, it is required to establish the whole set of modern infrastructures to control the breeding temperature and water quality, among which the heat supply and cooling facility is one of the most important facilities.

At the moment the company has three LSLGF-500 screw compressors, one deep geothermal well and one shallow fresh-water well, which are applied to the cooling and heating system of the aquaculture. With the development and expansion of production , the original facility cannot meet the new needs of the aquaculture requirements of the company. In addition, the original heating and cooling system often consumes a great deal of energy, which results in a high breeding cost and poor economy.

In order to attain the goal to develop the geothermal resources reasonably and to utilize the geothermal energy in a sustainable manner, based on the local natural resources, the company decided to employ the deep aquifer thermal energy storage technology to transform the original heating and cooling system to increase the loading capacity. On one hand, this technology can meet the aquaculture production needs of the company, and on the other hand, the technology can develop and protect the geothermal resources to attain the goal of high efficiency and energy saving.

3.2 Technological process

3.2.1 Cooling technological process

Tianjin Haifazhenpin Company uses the fresh water well as the cooling resource during the aquaculture cooling process, employing the screw compressors for the peak requirements , i.e. setting the water source heat pump to cool down in two stages and cooling the water body in the water treatment pool through the coiled pipes. When the cold load is approaching the peak value, the original screw compressor set ((LSLGF-500)) is used to regulate the peak value. This process is shown in Figure 1.

In the new system a new shallow fresh water well(with a depth of 240m) is used to cooperate with the original fresh water well to perform the exploitation and recharging process at the same time (i.e. Well 1 is used to pump water, and the water temperature inthe first summer is 19°C; Well 2 is used to recharge water, and the recharging water temperature is 24°C to 28°C), and the two shallow fresh water wells will be used as the cooling resource for the water source system of the heat pump set (that is to say, such a process will create the favorable conditions for the heat supply in winter). If the company is to expand the production scale, it can build a shallow salt water well (with a well depth of 100m) to recharge the cold seawater with a temperature of -1°C and 1°C between December and February, and the water will be adopted as the cooling resource between June and September.

In addition, it is advisable to start the water source heat pump to perform refrigeration in the two months, from the middle of May to the middle of June and from the middle of September to the middle of October. The hot water produced during the cooling process can be used as the hot medium to heat the water treatment pool for the high-temperature fish, which can be of great efficiency and remarkable benefit.

3.2.2 Heat supply technological process

For the aquaculture heat supply in Tianjin Haifazhenpin Company, the combined heat resource of the energy storage well and the geothermal deep well shall be adopted. At first, build one fresh water well according to the cooling scheme to match with the original fresh water well; one is for the exploitation, and the other is for the recharging operation. Start the two heat pumps to raise the temperature by two steps. At this point, the exploitation and recharging well is reverse to the cooling scheme. Use the recharging well in the cooling scheme (Well 2) as the pump well for the heat supply of heat pump (because of the temperature promotion of cooling water during the refrigeration, the water temperature in the well becomes 23°C ~ 27°C), but employ the pump well for the refrigeration of the heat pump (Well 1) as the recharging well for the heat supply of heat pump. Next recharge the cooled water (with the water temperature of 15°C to 18°C) to facilitate the refrigeration use in the summer. Such a process forms a good circulation of cooling water and promotes the working efficiency of heat pump set. As the air temperature drops, the heat load will increase accordingly; as the heat is supplied by the water source heat pump, the hot water directly from the geothermal well can be used to mix the water to meet the conditions of fish culture. In a similar manner, when the company is to expand its scale, it is advisable to add a water source heat pump in the second-stage project to cooperate with the two water source heat pumps in the first stage. The technical process is described in Figure 2.

When the extreme case occurs, on the one hand, the large-flow rate driving pump can be employed temporarily to enlarge the exploitation amount of the geothermal water, on the other hand, considering the rather high costs in the extreme heat load case, it is advisable to reduce the heat needs by cutting down the aquaculture amount.

3.3 Project scheme and the realization

Haifazhenpin Co. Ltd. has two aquaculture workshops now; workshop 1 has 14 groups of water treatment pools (the volume of each water treatment pool is 168m^3, and the circulation water quantity of each water treatment pool is 80 m^3/h); workshop 2 has 24 groups of water treatment pools (the volume of each water treatment pool is 168m^3, and the circulation water quantity of each water treatment pool is 128 m^3/h).

The living water temperature for the *paralichthys oliuaceus* is between 2°C to 27°C; the optimum growing water temperature for the fry and the young fish is between 17°C to 20°C, and the optimum growing water temperature is 16°C to 21°C. The optimum living water temperature for the *flatfish* is between 21°C to 23°C. The calculated value of the aquaculture water temperature for the above two low-temperature fishes is 20°C±3°C. However, the *epinephelus drummondhayi* belongs to the high-temperature fish; its optimum growing water temperature is between 25°C to 20°C, and the calculated value of the aquaculture water temperature is 27°C±3°C.

According to the related technical specifications for the seawater aquiculture and by combining the experiences of Tianjin area, the hot (cold) parameters for various parts of the system, and the calculated parameters and the hot (cold) loads are given in Table 2.

3.3.1 System operation scheme

Because the outside temperature varies with the seasons, the operation of the heat supply and cooling system can be adjusted according to the variation of the outside temperatures. The scheme is as follows:

1. From the middle of September to the middle of November and the middle of March to the middle of June, parts of the heat pump set are started to heat the water body in the water treatment pools of the low and high-temperature fish aquaculture workshop through the coil pipes, utilizing the energy storage well.
2. From the middle of November to the middle of March, the heat pump set is used to heat the water body in the water treatment pools of the low and high-temperature fish aquaculture workshop through the coil pipes. As the air temperature decreases, the heat load will increase accordingly; at this point, pump a proper amount of hot water from the geothermal well and mix with the water body in the water treatment pools of the low and high-temperature fish aquaculture workshop according to the ambient temperature so as to meet the water temperature requirements for the growth of the high and low-temperature fishes.
3. In May, June and September, pump the low temperature water from the fresh water well or the cold sea water in the salt water well to make the water temperature in the water treatment pool of the low-temperature fish aquiculture workshop within the optimum water temperature range for the growth of the fish.
4. In June to August, start the cooling process of the heat pump set to cool down the water body in the water treatment pool of the low-temperature fish aquiculture workshop through the coil pipes. When the cold load is near the peak value, start the original screw compressor (LSLGF-500) to meet the peak.

In addition, as an adjustment measure, pump a proper amount of low-temperature water from the fresh water well or the cold sea water in the salt water well and mix with the water in the water treatment pool of the low-temperature fish aquaculture workshop to meet the water temperature requirements for the growth of low-temperature fish.

5. During the cooling process, the condensed hot water can be used as the heat medium to heat the water treatment pool for the high-temperature fish.
6. In December to February, store the cold water with the temperature of -1°C ~ 1°C in the salt-water well to create the conditions for the cold water mixture in summer.

3.3.2 Realization of the scheme

Synthesizing the above two cooling and heat supply schemes and combining the development scale of the company, the system transformation project can implemented in two steps (i.e. divided into two stages of projects); the first-stage project will provide experiences for the second-stage project, and the second-stage project will develop and improve on the first-stage project.

In the first-stage project, build a new fresh water well (with the depth of 240 m) to form the coupled-well exploitation mode of "one exploitation well and one recharging well" together with the original fresh water well to achieve the energy storage function. At the same time, install two water source heat pumps of 0.4 MW and combine with the energy storage well for the cooling in summer and the heat supply in winter. When the cold load reaches the peak value, use the original screw compressor set (LSLGF-500) to meet the peak state, and the original deep geothermal well can be used for the heat supply peaking in winter.

As the aquaculture production scale of the company increases gradually and the heat and cold load cannot meet the required needs any longer, it is advisable to implement the second-stage project. In the second-stage project, build one shallow salt water well (with the well depth of 100m) to store the cold sea water from December to February (-1°C to 1°C) as the cold resources for the cooling in June to September. At the same time, install one water source heat pump of 1.0 MW to cooperate with the two water source heat pumps of 0.4 MW established in the first-stage project to perform the function of cooling in summer and heat supply in winter.

3.3 Efficiency analysis

3.3.1 Environmental efficiency

The heat supply and cooling energy for the Tianjin Haifazhenpin Co. Ltd is a clean energy free of contamination. Compared with the traditional heat supply and cooling manner, there are no waste gases discharged during the operation of the system. The reduced discharge amounts of sulphur dioxide, nitrogen oxide, carbon dioxide and coal dust respectively are 4 800kg, 1 440kg, 160m^3, 1 120kg.

3.2 Economic efficiency analysis

The economic efficiency mainly includes the operation costs and the engineering investment. The engineering investment mainly includes the equipment costs for the water source heat pump and other facility, the drilling costs, power distribution transformation costs, the contingency costs and other related costs. The total engineering investment is 181 800 RMB; the investment on the first-stage project is 893000 RMB, and the investment on the second-stage project is 925000 RMB. The operation costs of the system mainly include the electric charge, the geothermal resource charge, labor cost, water charge and other related costs.

The operation costs of the first and second-stage project are given in Table 3. In Table 3, the heat supply capacity of the heat pump set in the first-stage transformation project is rather small (under the worst conditions, the supply capacity cannot meet the needs and it is required to take special measures), so the running costs are very small. At the same time, the running conditions of the refrigeration system and the costs for it in the period with high temperature during one year (from the middle June to the late August in summer) and the costs have been compared, and the results are given in Table 4.

Table 4 shows: during the two and a half months of operation period from the middle of June and August of each year, the cost for unit refrigeration amount in the first transformation scheme is 82.7% of the original refrigeration system, and the cost for unit refrigeration amount in the second transformation scheme is 46.4% of the original refrigeration system. The average monthly operation cost of the first-stage transformation scheme is 70.4% of that of the original refrigeration, and the average monthly operation cost of the second-stage transformation scheme is 54.6% of that of

the original refrigeration system As regards the total refrigeration capability of the refrigeration set and the shallow water wells, the capacity of the first-stage transformation scheme is 87.7% of that of the original refrigeration system, but the capacity of the second-stage transformation scheme is 181.6% of that of the original refrigeration system.

4 CONCLUSIONS

The heat supply and refrigeration system of Tianjin Haifazhenpin Co. Ltd., transformed with the deep aquifer thermal energy storage technology cannot only meet the engineering needs, but also make the low-grade energy resources (such as sea water, underground shallow salt water, and so on) fully utilized, which brings significant social and economic benefits, attains the goal of high efficiency, energy saving and sustainable exploitation and utilization.

Because the industrialized seawater aquaculture is a new production mode in China, there is a lack of the mature experiences. Especially there is lack of a set of complete and accurate data for determining the heat and cold loads of the water body in the aquaculture workshop, the temperature variation laws of the water body in the water treatment pool. Therefore, after the implementation of the first-stage transformation scheme, it is necessary to take a series of experiments to explore the operating conditions of refrigeration and heat supply system according to the present operation situation. The experimental results, and the scientific conclusions to be drawn will provide reliable design parameters for the implementation of the second-stage transformation scheme, and valuable references for future similar heat supply and refrigeration projects for industrialized aquaculture.

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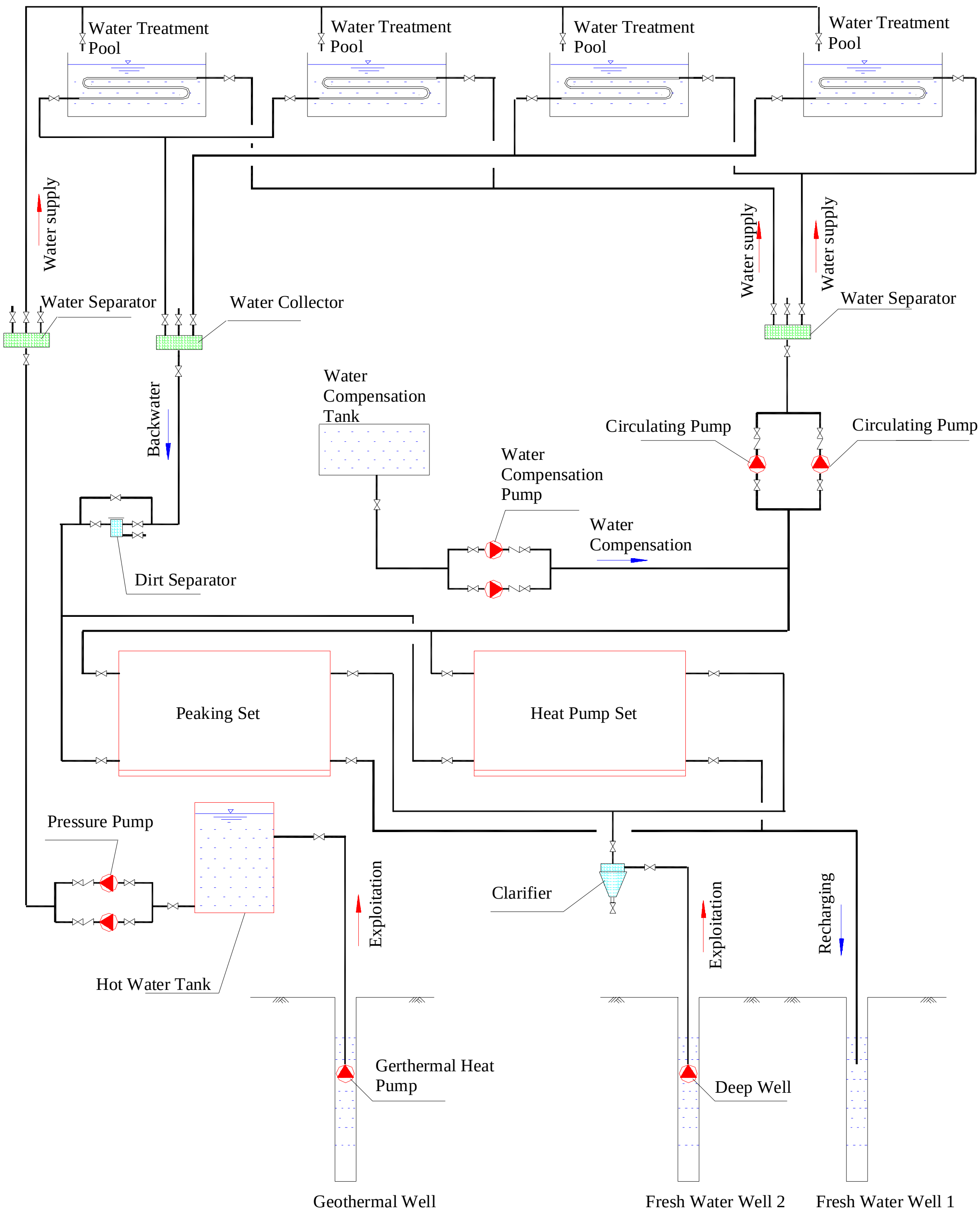

Fig.1. The refrigerating technical chart

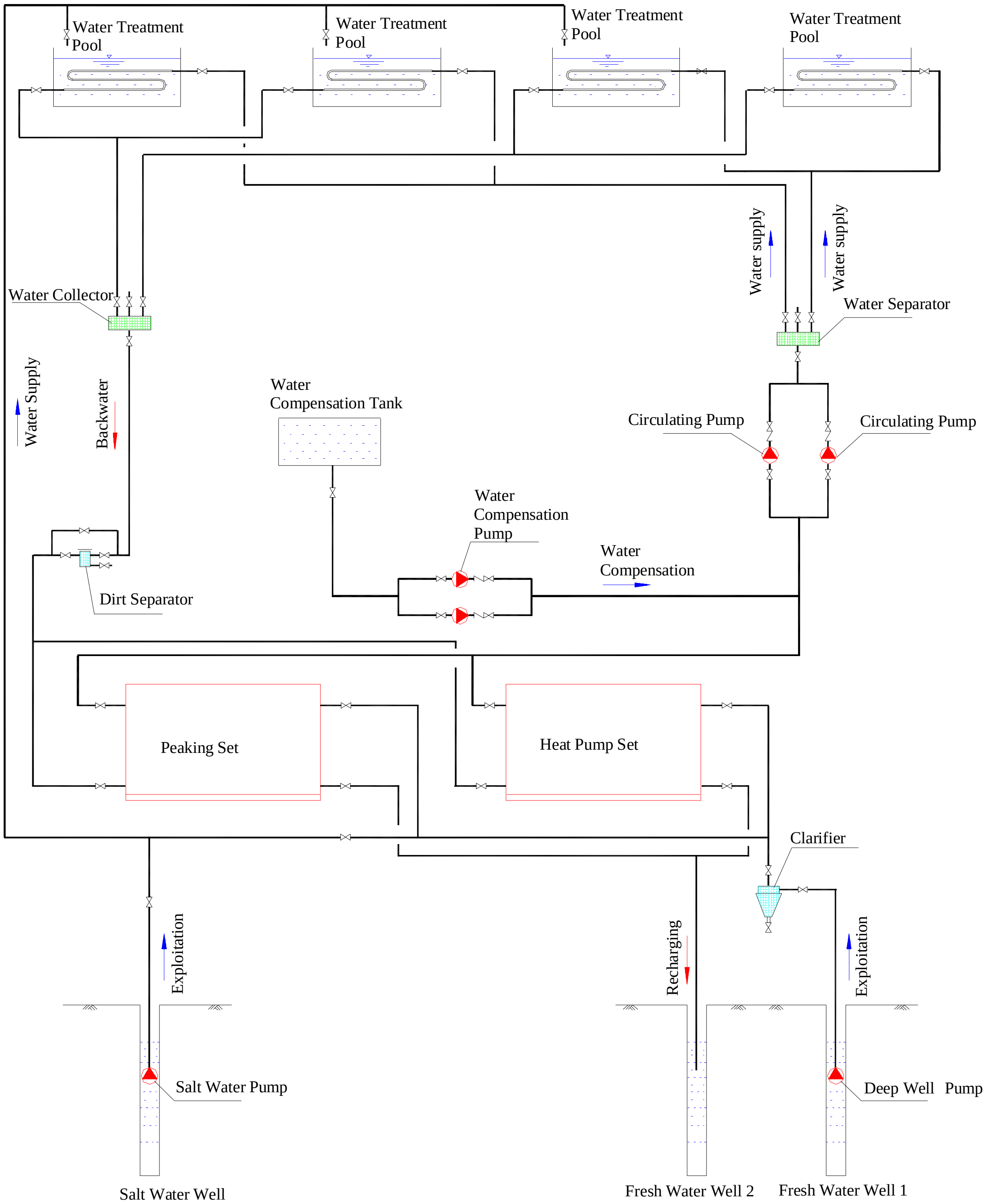

Fig.2. The technical chart for heating

Table 1 Strata of this area from the lower upward

The middle and early proterozoic group	—	—
Palaeozoic group	cambrian system ordovician system Permo-carboniferous system	—
Mesozoic group	jurassic system	The maximum thickness of 428m
	cretaceous system	The thickness of 452m
cenozoic group	Kongdian Formation of palaeogene system	The thickness of 415m
	Shahejie Formation of palaeogene system	The maximum thickness of 1758m
	Guantao Formation of neogene system	The thickness of between 148 and 500 m, fluvial settlement
	Minghuazheng Formation of neogene system	The thickness of between 270 and 870 m, sandstone and mudstone
quaternary system	The lithology is khaki to light gray clay, silty and fine sand, light yellow sandy clay with various thickness, muddy sand layer	The thickness of 330 to 530m

Table 2 The heat and cold loads of the system

Name	Circulation water quantity (m^3/h)	Differences of the water at the inlet and outlet (°C)		Water pool number	Heat loads (kcal/h)	Cold loads (kcal/h)
		For heat supply	For refrigeration			
Aquiculture workshop 1	80	1	0.4	14	1,120,000	448,000
Aquiculture workshop 2	128	1	0.4	24	4,192,000	1,228,800
Fry breeding workshop	—	—	—	—	273,000	120,000
Office and research building	—	—	—	—	84,000	-
Total	—	—	—	—	4,549,000	1,377,600

Notes: Considering the low-temperature fishes account for 3/4 of the total, multiply the cold loads of aquiculture workshop by 0.75 during the calculation.

Table 3 The annual operation costs of the system

Operation costs	First stage project	Second stage project
Heat supply operation costs (10000 RMB)	546,694	685,928
Cooling operation costs (10000 RMB)	396,526	307,986
Total □ □	943,220	993,914

Table 4 Comparison of operating costs for refrigeration in summer

Serial No.	Item name	First stage project	Second stage project	Original refrigeration system
1	Refrigerating capability of machine set (Kw)	1250	1730	1470
5	Cooling capability of well water (Mw)	320	1520	320
6	Real total refrigeration capability (Kw)	1570	3250	1790
2	Total operation costs (RMB)	396526	307986	563602
7	Notes	One machine for two purposes, refrigeration in summer and heat supply in winter	One machine for two purposes, refrigeration in summer and heat supply in winter	Only for the refrigeration machine set.