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Three Major Problems with Geothermal Heating in China

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ABSTRACT

The coastal area along the edge of the Pacific Ocean in eastern China is rich in low temperature geothermal resources. There are a high number of cities in this densely populated area, resulting in the existence of a stable heating market. During 2004, the geothermal space heating area of Tianjin city alone has reached 10,000,000 m^2.

Three main issues need to be solved concerning the use of geothermal space heating in China. Firstly, the development has to be sustainable. Geothermal energy is renewable only when it is not over-exploited. The exploitation of geothermal energy needs to be regulated by the local council and a reinjection plan should be put into place. Secondly, an anticorrosion geothermal heating system needs to be employed. Thirdly, a geothermal heating project needs to be financeable, profitable and competitive to the conventional heating project.

20 years of geothermal utilization in China has exposed a number of issues and, at the same time, given rise to a lot of successful experiences. Summarizing from the practical experience gained from the metropolis and cities, well exploitation and good use of geothermal energy is achievable if there is a correct guiding principle, good management, a rational exploitation program and technical approach, and a proper use of the finance and business operation. Why is it that in China a well as deep as 3000m can be used solely for space heating? The key point of this paper is to point out the features of how to finance a geothermal space-heating project in China.

1. SUSTAINABLE UTILIZATION OF GEOTHERMAL RESOURCES

In recent years, both the growth rate and absolute value of geothermal space heating in China has been the fastest of any county, which is mainly attributed to the drive for business profit. If proper management and control are not available, there will be adverse consequences for resource renewability and the environment of the exploited areas which will be difficult to remedy in the short term. Whether the geothermal heating can be sustainable has been the problem facing such areas as Beijing, Tianjin, Xi'an and Lindian in the Daqing region, being particularly severe in some of them. Most of the geothermal wells in proterozoic basement rock exploited more than ten years ago in Tianjin area were artesian. At present, the hydrostatic level there has dropped to 60 meters or so beneath the surface, while the dynamic water level is around -100m. What is more, the above water level is falling at roughly 6 meters per year on average. In Xi'an and Daqing Lindian, it reached the point that the geothermal water in some wells was nearly exhausted and the underground and surface engineering facilities were close to being abandoned. In the face of this, people question whether the geothermal is a renewable or not. Geothermal renewability is based upon the huge quantity of heat inside the earth. Nevertheless, only a very small amount of geothermal is available and utilizable in areas of habitation. Quite a few natural hot springs all over the world have been free from attenuation for many centuries, which testifies to its renewability. Clearly, what lies behind that is the balance established between the surface drainage and heat supplement from deep underground. Where geothermal is heavily exploited for space heating in urban areas in China, beyond the limit of natural recharge, sustainable utilization will be gravely affected and the resource may be used up rapidly.

Sustainable development must be backed by renewability, while sustainable exploitation can only be obtained from renewable sources. Sustaining an operation is impossible in the absence of renewal capacity. The geothermal resource possesses the capability to renew although, under long term excessive exploitation beyond the renewal capacity, the source will be damaged and further exhausted, making the sustainable development null. On account of this, the renewal capacity of a resource must be strictly observed during use in order to sustain such utilization.

Geothermal resources can be either convective or conductive. The hot water in all the major basins in space heating areas in the north of China is contained in sedimentary formations. Heat replenishment is low, being entirely conductive, restricting the renewal capacity of geothermal.

Hydraulic and thermal cones of depression are formed in the underground reservoir during the process of geothermal exploitation, leading to a re-establishment of pressure and temperature gradients. With the increased temperature difference, the heat- renewal capacity of the reservoir increases correspondingly by an "increment", and then reaches a new stable status. After a certain time, water temperature will become relatively stable. Thus, extraction can be continued further. As long as this "increment" is scientifically and moderately utilized, the exploitation can be sustainable. Where there is insufficient information, technical capacity or experience, the exploitation should be initiated from a low level on a small scale, with an exploiting level limit index set. No excessive exploitation should be allowed.

Doublet reinjection technology should be adopted to intensify the exploitation. Natural recharge alone is often far from sufficient to meet the demand of users and business. For the purpose of simultaneously enhancing yield and maintaining sustainability, the technology of doublet reinjection may and should be applied so as to improve the intensity of geothermal exploitation. Practical experience from other countries shows that this technology is an effective way of elevating reasonably the intensity of geothermal exploitation.

Reinjection will start to restore the reservoir pressure in a very short time, allowing the reduction of subsidence that might arising from geothermal exploitation. In addition, reinjection can avoid discharge of the geothermal fluid to the surface after use, and further prevent such drainage from polluting the environment.

In the area of Tianjin, to control the over-fast drawdown prior to 2002, 11 groups of doublets have been installed. These have three objectives: reinjection in the same layer, reinjection in a different layer, and two production wells plus reinjection, from which basic experience has been gained. According to this experience, there are generally many problems with porous reservoirs, and it is most likely to be feasible to reinject by gravity after the reduction of sub-surface pressure.

The common situation presently in China is that exploitation is done without reinjection. Domestic hot water and business hot springs are the only market for exploitation in the south city areas where no space heating is employed. There is normally no cold water to be reinjected after use. In such areas, the utilization of the resource can be sustained only by strict limitation of the exploitation quantity. Otherwise, the reservoir pressure will descend speedily, except in the rare circumstance that the resource has a natural replenishing capacity far greater than the quantity of fluid and heat extracted. In some parts of China, water levels of geothermal wells once decreased by around 10m or even more per year on average. The long utilization without consideration of the resource sustainability is of nothing more than destructive exploitation.

2. SYSTEM ANTICORROSION

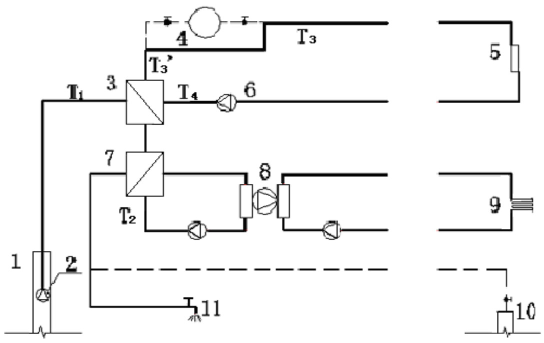
In China, the geothermal fluids used for space heating are mostly exploited from deep wells 1500 meters beneath the surface. The geothermal water is corrosive to metal, and corrosion is common and often very severe. Chloride ion (Cl^-) is the most common component that plays the main corrosive function in geothermal fluid. Its content is generally between 300mg/l and 800mg/l.

To prevent corrosion, the indirect space heating system with heat exchangers should be adopted. The sketch of an indirect geothermal heating system as shown below indicates that the geothermal corrosion will be localized within the wellhead and heat exchanger. If a heat exchanger is not used, the following situations will occur:

1. The system will corrode.
2. The space heating system is open and drain outwards continuously. So some vertical pipes in the system empty easily and the resulting loss of water causes interruption of the space heating. That is to say, the system has a poor hydraulic stability.
3. The quality of geothermal fluid will deteriorate by contamination after flowing through heating system, affecting subsequent utilization. Such polluted fluid also should not be used for reinjection.
4. The flow and temperature of geothermal fluid are often not in accordance with the water quantity and temperature drop required by the heating system.

At present, in China, heat pumps are adopted in a few geothermal space heating system before the discharge in order to improve the rate of geothermal utilization.

Some users of geothermal space heating in China are reluctant to use heat exchangers. They think that omitting the heat exchanger will eliminate the heat loss incurred by the temperature differential and, in the meantime, investment in the heat exchanger can be saved. The direct geothermal heating is realized by delivering geothermal fluid directly into the user terminal radiators. Initially it seems that this kind of heating system has advantages such as low investment, relatively full utilization of geothermal heat, etc., but severe corrosion entails more maintenance of the system, and even brings about the breakage of equipment and pipes. Owing to the corrosion by geothermal, some direct geothermal heating systems are damaged after no more than two or three years of use and the users have to replace them with large economic losses.



geothermal indirect heating system

1.production well 2.submersible pump 3.heat exchanger
4.peaking boiler 5.cast iron radiator or fan coil
6.pump 7.heat exchanger 8.heatpump 9. radiant

It is often thought that so long as oxygen is kept out of the system, chloride ion corrosion can be avoided. But the actual situation is that corrosion will occur when even tiny quantities of dissolved oxygen exist. It is scarcely possible to isolate a practical heating system completely from oxygen. For this purpose, addition of reagent is adopted in some systems, so further capital investment in reagent adding equipment and operating expenses on reagent addition are involved. The use of such methods is usually abandoned due to difficult operation or high cost.

Considering that the geothermal temperature is not very high and the temperature difference across the heat exchanger is small, and in order to facilitate opening the exchanger and observing its corrosion situation as well as removing scale, plate heat exchangers are normally used used. Either stainless steel or titanium can be used, and the cost of stainless steel is about one half that of titanium. Nevertheless, among approximately one hundred geothermal space heating projects completed by us in the past, in only about five per cent of cases is the geothermal water suitable for using stainless steel to resist corrosion. Hence, mostly, only titanium plate heat exchangers can be selected. The capital cost of titanium plate heat exchangers is US$ 0.25 to 1.0 (US$ 1.0 =RMB 8.27) per square meter of residential space heating floor area. The apportioned cost is in inverse proportion to the geothermal temperature. The heat loss by conductive temperature difference is 5%-15%. The heat loss percentage diminishes with increasing geothermal temperature. According to experience, in order to protect the system from rapid corrosion, indirect space heating is almost the only normal and reasonable means. Otherwise, it is likely that the gains cannot offset the losses.

3. ECONOMIC BENEFIT AND SUSTAINABLE DEVELOPMENT

3.1 Cost of geothermal space heating

The investment and operational cost status involved in the case of only a production well without reinjection and another case with reinjection are as follows (see Table 1).

3.1.1 Initial investment

Initial investment on the geothermal well: US$ 157.2/m ($13^3/_8$"×$9^5/_8$"or7") for production well and reinjection well for an average well depth of 2000m and 3500m.

Geothermal station: includes expenses on submersible pumps, wellhead variable frequency converters, titanium plate heat exchangers, circulation pump and civil works, etc.

3.1.2 Floor area of space heating

Each well can supply heat for 72,000m^2 of space heating floor area, based on the following conditions: the flowrate of the production well is 100m^3 per hour; the wellhead temperature T_1 is 70°C; the discharge temperature after heat release T_2 is 45°C, giving a temperature drop of 25°C. The water temperatures in the circulation system T_3 and T_4 are 62°C and 42°C respectively. In areas where the heating requirement is about 2000 degree days, the design load of residential space heating is 40W/m^2.

3.1.3 Production costs

Include costs involved in geothermal resources, water, electricity, wages and welfare, depreciation and repair.

The costs of geothermal resources, water and electricity are US$ 0.122/m^3, US$ 0.122/m^3, and US$ 0.06/kWh respectively. The cost of depreciation is calculated as 95% of initial fixed assets investment divided by 20 years, and the annual repair cost is calculated as 1.5% of the fixed assets.

Expenses on management include costs of fluid disposal, labor union, training of employees, marketing and taxes, etc.

The disposal cost is US$ 0.036/m^3, and the expenses on labor union and employee training are calculated as 3.5% of wages. Other management expenses and taxes are calculated as 4% and 5% of the sales respectively.

Total production cost C= production cost + management expense + financial expense + business expense.

Table 1

Initial investment of systems in US$					
		2000m deep		3500m deep	
		No reinj.	Reinj.	No reinj.	Reinj.
Production Well		314,389	314,389	550,181	550,181
Geothermal Plant		90,689	96,735	108,827	108,827
Reinjection well			314,389		550,181
Sum	I	405,079	725,514	659,008	1,209,190

O & M Costs in US$					
Resources Fee	c1	25,944	25,944	25,944	25,944
water and eletricity	c2	22,831	28,877	22,831	28,877
Wages and welfare	c3	8,271	8,271	8,271	8,271
Depreciation	c4	19,241	34,462	30,441	51,693
Maintenance	c5	7,315	12,424	7,315	12,424
discharge Fee	c6	7,783		7,783	
management and sale	c7	5,654	5,654	5,654	5,654
tax & duty	c8	5,400	5,400	5,400	5,400
sum up Σ c1:c8 = C'		102,439	121,032	113,639	138,263
Heating Floor Area A m^2		72,000	72,000	72,000	72,000
C'/A	US$ /m^2	1.42	1.68	1.58	1.92

Original Capital 20year Recovery					
$(A/P_{,i,n})_{20yr.}$	i=5%	0.080243	0.080243	0.080243	0.080243
$I\ (A/P_{,i,n})_{20yr.}$		32,505	58,217	52,881	97,029
Annual Cost AC=I($A/P_{,i,n}$)+C'		134,944	179,249	166,520	235,292
AC/A=ac ,	US$ /m^2 yr.	1.87	2.49	2.31	3.27

Original Capital 10year Recovery					
$(A/P_{,i,n})_{10yr.}$	i=5%	0.129505	0.129505	0.129505	0.129505
$I\ (A/P_{,i,n})_{10yr.}$		52,460	93,958	85,345	156,596
Annual Cost AC=I($A/P_{,i,n}$)+C'		154,899	214,990	198,984	294,859
AC/A=ac ,	US$ /m^2 yr.	2.15	2.99	2.76	4.10

3.1.4 Total operational costs C'

Besides direct costs, the actual heating price should also include marketing expenses and various taxes, which now are uniformly calculated into the management expense. Then the total annual operation expense C' is constituted after summation.

$$AC = \sum_{t=1}^{n} (I + C' - S_v - W).t.(P/F_{i,t}).(A/P_{i,n})$$

Where: I = total investment, C' = total annual operational cost, S_v = calculated fixed assets surplus at the end of period, W = calculated recovered flow capital at the end of period, $(P/F_{i,t})$ = discount coefficient, n = calculation period, i = interest rate, $(A/P_{i,n})$ = capital recovery coefficient.

Actually in geothermal engineering projects, the calculated fixed assets surplus at the end of period S_v and the calculated recovered flow capital at the end of period W only account for a very little share. After omitting (Sv+W), AC = I.$(A/P_{i,n})$ + C'. AC is the average annual amount due to repay based upon consideration of compound interest in the calculation period, i.e. annual expense AC = initial investment x capital recovery factor + total annual production cost. Here, i=5%, n=20 years, $(A/P,_{i,n})$ = 0.080243; alternatively, take n = 10 years, $(A/P_{i,n})$ = 0.129505.

Annual expense per square meter = annual expense / space heating floor area.

3.2 Impact out of economic benefit

According to the above calculation, for a 2000-meter-deep doublet system, the initial investment can be completely compensated after 20 years, and the annual expense for space heating is US\$ 2.5/m^2, which is hard to compete with coal-burning space heating. But it is still neck and neck compared with gas and heat pump space heating systems. On this account, it is reasonable and feasible that areas with appropriate conditions should undertake capital planning and make provision for reinjection wells. If we assume that the initial investment is compensated within 10 years, the annual expense for space heating should be US\$ 3.0/m^2, which will have difficulty in competing with space heating by conventional energy sources. To apportion the initial investment for reinjection wells into the building is workable as the amount is not very high.

In case that the depth of doublet is increased to 3500m, and the initial investment is required to be compensated within 10 to 20 years, the corresponding annual heating expense is from US\$ 4.1/m^2 to US\$ 3.27/m^2, making it even more difficult to compete with space heating by conventional energy sources. Even if no reinjection well is adopted, the relevant annual heating expense is still as high as US\$ 2.76/m^2 to US\$ 2.31/m^2.

For one production well of 2000m without a reinjection well, under the assumption that no compensation is required for initial investment, the annual expense for space heating is US\$ 1.43/m^2 year. Because no reinjection is required, the geothermal fluid can be sold. So the domestic hot water is supplied normally with full-year load. If we estimate roughly that the annual price of space heating US\$ 1.944/m^2, and assume that 25% of the hot water can be sold at the price of US\$ 0.486/m^3, about US\$ 133,660 of profit per year may be gained by this well, which is apparently of colossal profit. Furthermore, if there is no normal depreciation allowance in the cost, that profit will be of super windfall. This is why geothermal resources are increasingly exploited irrespective of damage to the environment and at the risk of resource exhaustion in many places. Normally, unless the commonweal projects are given investment subsidy by the state, it is impossible that a project can survive without compensation for the initial investment in a market operation. Where, then, does the fund come from? The answer is that it has been included in the selling price of the residence, in some instances, commercial operation for hotspring garden residences makes the profit even higher. While the selling prices of geothermal space heating and fluid are based on those of conventional energy sources, it is generally neglected that the geothermal heating price should be calculated without the initial investment paid by the customer, which is the main origin of the profit.

In some cities in China, some low-temperature geothermal wells with depths up to 3000m around are developed. Such wells are rarely seen in other countries. This is because the initial investment is often extra high as a result of the well's great depth and corrosion inhibition is needed by the heating system. Except for projects with unusual resources and superior conditions for use, the financial analyses often show no feasibility. Another important reason for the appearance of deep geothermal well projects lies in the non-adoption of reinjection wells and no requirement to repay the initial investment. Consideration that drilling deep wells to exploit geothermal for commercial tour and balneological use can bring high economic benefit, such projects are feasible as the huge investment in well drilling is acceptable to the market. But the investment for reinjection wells should be planned and prepared.

3.3 Draw up codes and take control measures

Owing to big difference in both geothermal resources and utilization status, the gap between investment and yield can be so considerable that it would not be accepted when investing in other industries. Therefore the economic benefit of different industries can vary greatly. In the presence of abundant financial benefit, the resources cannot be robbed wantonly. Over-exploitation will inevitably bring about the exhaustion of the resources that will be difficult to recover in the short term, presenting a risk of disappearance. The drive of economic benefit often is the main factor causing the damage of resources and environment. This should be solved by dint of legislation and economic means.

While providing social benefit, developing geothermal will also involve a great deal of social cost. Some social costs may have no evident and direct relationship with the investors and consumers, but capital must be invested for it. For instance, establishing a resource variation database and organizing reinjection are all complex works, failing which the resources may be destroyed. It is reasonable that pre-phase expenditures should be backed by resource expenditure so as to pave the way for the sustainable geothermal exploitation.

4. CONCLUSION

- Geothermal energy used for space heating in the north of China is a limited renewable energy source, of which the exploitation should be strictly restricted. By using doublet reinjection technology, the intensity of geothermal exploitation can be enhanced and it would be possible to extend the areas where the geothermal is utilized on a sustainable basis.

- For the sake of preventing the system from being corroded by geothermal, indirect space heating with heat exchangers is almost the only normal and reasonable method. Otherwise, it is likely that the loss outweighs the gain.

- Analyzing the investment and yield in relation to geothermal heating, it is concluded that under a lot of instances drilling reinjection wells is reasonable and feasible economically.

- Unreasonable geothermal heating profit is the important cause of excessive well drilling and overmuch exploitation. By way of drawing out and executing local control code and adjusting resources expense and tax timely to lead to a reasonable profit of geothermal project, it is possible to raise the capital for reinjection wells as well as regulate and control the speed of development.