Successful Application of ATES/Groundwater Source Heat Pump in China

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Successful Application of ATES/Groundwater Source Heat Pump in China

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Abstract. The short lifespan of wells and groundwater re-injection problems baffles the ATES/GWSHP application. A new effort has been made by introduction of matured ATES technology for the two projects in China. The initial results indicate that high quality well and sustainable groundwater re-injection can be realized.

Introduction
After more than decades groundwater source heat pump (GWSHP) development, many negative stories appear about well quality and clogging problems, such as groundwater injection problem, waste of groundwater, short lifespan of wells, land subsidence and collapse, which is almost same as what happened to Chinese ATES in late 1990s described by authors at Terrastock 2000. At this moment, the clients lose their trust, the local governments once actively promoted, become more suspicious such application

On the other hand, two groundwater related projects have been successful realized recently. One is ATES application in a modern greenhouse project in Shanghai with two cold wells and two warm wells. The system was almost fully imported under framework of Sino-Dutch cooperation program. After one and half year’s operation, the groundwater re-injection is still stable, no clogging of wells has be found. The other is a groundwater system renovation for a heat pump project in Hubei province. The system was once suffered from groundwater re-injection problem and high sand content of the extracted groundwater. The renovated groundwater system with a doublet wells was established by ATES technology and started to operate before the winter of 2014. According to measurement, no clogging has been found and groundwater is sand free. In both case, the extracted groundwater has been fully re-injected.

The success of two groundwater related energy projects indicates sustainability of ATES/GWSHP project could be reached by new technology and quality control. To ensure the energy sustainability, some professional software, such as MODFLOW, has to be adapted for ATES/GWSHP system design.
Experience in China and Abroad

China was the first country for large scale application of ATES which dated back to early 1960s (Shanghai Hydrogeology Team, 1977). Chinese ATES system was characterized with the aquifer replenishment with cold surface water at winter season, and through flow cooling with groundwater during summer as shown in figure 1. Shanghai style ATES was faded away in later 1990s, partly due to the defects that the groundwater was polluted by surface water, high fluctuation of change of seasonal groundwater level, and waste of the water resource (Xiaobo et al, 2000). Nevertheless, ATES had been studied quite extensively, both theoretically and experimentally, especially the mechanism of well clogging and its re-generation, well design and construction etc..

Inspired by ATES development in China, and also due to energy crisis, numbers of western countries began to explore ATES for efficiency use of the energy in 1970s. A Bimonthly review of aquifer thermal energy storage new letter was established with title of STES, Seasonal Thermal Energy Storage, sponsored by U.S. Department of Energy though Oak Ridge National Laboratory. Many Shanghai ATES related literatures were translated into English, and several ATES trial projects were implemented (STES NEWSLETTER, 1978 to 1986). Then, the first international conference on thermal use of ground was convened in 1979, with number of papers on UTES (EHPG-CTH, 1979). During the meeting, the International committee on Thermal Energy Storage (ICTES), which late was taken over by IEA ECES program, was established, resulting in so called “Stock”-conference periodically every 2 or 3 years. Within the framework of IEA Energy Storage Program, an extensive report, Underground Thermal Energy Storage, state of the art 1994, was published (Bakema G. et al. 1995). For those projects, the concept of doublet groundwater system had been adopted which groundwater was extracted from one well, and re-injected to another well after its exchange heat or cold with above ground system, as shown in figure 2. However, it was found out, except the Netherlands, most of those ATES trial projects could not sustain for operation, whose problems were was similar to what happened to GWSHP in China now.

The introduction of GWSHP in China in early 1990s, was initiated by SINO-US cooperation framework on energy efficiency and renewable energy program, supported by a group of heat pump manufactures. Until 2008, more than 280 companies had been involved in ground sources heat pump (GSHP) business with 5000 realized projects among which 40% are GWSHP projects (Xu Wei, 2008). Most clients preferred to use GWSHP systems just due to its low investment in comparison with the soil source heat pump systems. However, the groundwater systems of GWSHP were not much different from that of ATES, from early through flow to extraction-reinjection way. The lessons of ATES could be also applicable for GWSHP (Wu X. et al 2003), such as well life span and groundwater re-injection problems. Being aware of those technical problems, some local governments, like Shanghai and Jiangsu, were cautious for such application. But most north cities, GWSHP were
promoted by local government, as an clean and alternative to the coal-fired boiler during for winter heating. It could be expected that groundwater system could not be sustainable without improvement of well quality and better solution of clogging problem. As the consequence, most projects were failed as reported by China Construction News (Zhao J. 2014). The market is ruined with low quality projects, low price competition and even corruption. Those early pro-active local governments for GWSHP began to limit such application, such as Beijing and Shenyang.

Figure 2 a doublet groundwater system of cold storage

On the other side of the world, it is noticed that ATES has been highly successful in the Netherlands. So far, more than 2000 ATES projects have been realized, and it is expected that number of ATES projects will skyrocket in next decade, 20,000 in the year of 2020 (Godschalk, B. and Bakema G. 2009).

The success of Dutch ATES, according to our communication with our Dutch ATES consortium during joint feasibility studies for potential projects at different region in China, was due to following reasons:

- Dutch has excellent aquifer for ATES application, where is found almost all major cities in the Netherlands;
- High density of buildings are suitable for large scale projects;
- The groundwater temperature level is suitable for direct cooling of ATES with high energy efficiency;
- The ATES engineering consultancy companies, which have comprehensive knowledge of hydrogeology, energy science, well construction, civil engineering and electric mechanical engineering, could provide total solution for system design, supervision, and commission which could avoid the risk and ensure the quality of the project.
- The high well quality could be ensured with advance drilling system, and good supply chain of high quality well construction materials.

**Technology Improvement and Knowhow**

Thermally use of groundwater as storage is more than groundwater extraction and re-injection. The energy expert needs to know the temperature level of heat or cold from the storage for his energy system. The hydrologist want to optimize the well locations to avoid thermal shortcut among warm and cold wells, and at the same time, keep both thermal and thermal hydraulic impact as minimum as possible. The thermal and hydrogeological modeling is needed for optimal design of ATES/GWSHP system.

Early studies on thermal and hydrogeological behaviour of ATES were done with some research projects based on simple numerical simulations. The typical one was to compare the simulation results of Shanghai ATES test facilities, with two cold wells, warm wells, 38 observation holes for
temperature and water level, and 27 land subsidence monitoring points (Sun. Y., et al. 1991), (Zheng Z., 1993). These fundamental research, showed that it was possible to simulate thermal hydrogeological field by numerical method. Due to limited computer speed and storage at early 1990s, such simulation could only be done with simple boundary situation with some assumptions. It was impossible for the prediction of ATES thermal behaviour which needed large simulation with complicated boundary conditions.

Now, more sophisticated hydrogeology simulation methods are available. HST2D/3D has been widely used for ATES design in the Netherlands. In our case, the code of MODFLOW USGS has been adapted for our application in combination of SEAWAT 4.0 modules, which counts influence of changes of density, viscosity, concentration of the water. Figure 3 is an example which shows the upper and lower boundary of the confined aquifer for energy storage in Shanghai ATES test field, and well locations and its screen positions.

![Figure 3 boundary of ATES test field in Shanghai.](image)

With the input data of groundwater injection rate and temperature, extraction groundwater flow rate, without any calibration of the model, the simulation of results of thermal response curve of extraction groundwater is in good agreement with field measurement data from the observation holes and ATES wells, as shown in Figure 4 for thermal response curve of ATES wells. There are some minor difference in temperature data between simulation and observation due to both measurement and calculation errors. But the accuracy more than efficient for ATES application. From designer point of view, the proper range of temperature is important for HVAC system calculation.

![Figure 4. thermal response curve by 3D SEAWAT with field observation data.](image)

The visualization of the dynamic of aquifer temperature profile could demonstrate the evolution of warm and cold water body near wells. Such dynamic visualization is very useful to quick check if the wells are allocated in proper ways in order to avoid thermal shortcut and efficient use of underground space, and also heat balance after many years operations. It is also useful to understand ATES thermal environment which is in somehow, never been monitored in practice.
As mentioned early, ATES/GWSHP needs high quality wells. However, the well quality standard for GSWHP in China is just referred to that of drinking water well, whose sand content of groundwater, about 1/200,000. While in reality, the well quality has hardly be checked, even worse. In order to prevent the solid clogging of the wells, the cyclone separator, or the deposit pool is always arranged in the typical groundwater system to separate those solid particles from groundwater, which usually is not always effective for prevention of clogging. Sometimes, the sand content of extracted groundwater is so high that clients worry about that the foundation of nearby buildings might be damaged.

The low well quality is related to many factors. Most of well casing and screen are made of steel which could be easily eroded or scaled. The sizes of slot of screen and backfilling gravel are not matched with the grain size of the aquifer, which could not block the fine sand from aquifer during extraction of groundwater. As the consequence, most well lifespan of ATES/GSWHP are quite short, mostly 3-5 years.

As for borehole drilling, like most of other countries, the traditional direct flush drilling system has always been used with a lot of clay or bentonide in drilling liquid to keep borhole stable, which results in very difficult to develop wells for ATES/GSWHP application.

To build a high quality well, the following improvements have be made:

- U-PVC or stainless steel screen or casing will be sued to prevent erosion, as show in figure 7. Usually, the U-PVC screen and case could be selected within 200 meter depth, due to its easy installation and low cost. The stainless steel screen is only used for deep well which needs high strength;
- The size of well sorted backfilling gravel and slot size of screen match with the grain size of the aquifer;
- The air-lift reversary drilling method is a good alternative for borhole drilling. In order to keep sand and mud content of drilling liquid as low as possible, three stage mud tank has been used to deposite and remove solid particles during drilling process. Figure 8 is the typical layout of air-lift reversary drilling system.

Conclusion:
Many problems related to groundwater source heat pump systems in China could be solved by improving well quality, ATES technology and user’s experience. The traditional water well technology is not suitable for such application. To better and sustainable use of aquifer and underground space, ATES is a good alternative to GWSHP. However, local regulation or even legislation for aquifer utilization which was based on obsolete technology, become bottleneck for ATES application in the major cities in China.

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