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PVC U-tube Drilling and Completion Technology in Shallow Geothermal Development

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ABSTRACT

Steel tubing is the traditional well tube material used in production and reinjection wells in shallow geothermal development but has some problems when used in GWHP's (Ground Water Source Heat Pumps) like corrosion and scaling. PVC-U tubing has several advantages over steel tubing: it is light weight, non-corrodible, and has a longer life time,. Because of the difference in physical properties between PVC-U and steel tubing, different drilling and completion technologies are used for each. Two PVC-U tube wells have been successfully completed to depths of 400 m and 437 m. This project broadens the application of PCV-U tubing and contributes to some key areas of interest in drilling and completion technology, including well structure design, "balance pressure" completion well technology, and accident solutions.

1. INTRODUCTION

The GWHP system plays an important role in the shallow geothermal energy utilization projects. Traditionally, steel tubing is used in production and reinjection wells in GWHP systems but has some shortcoming such as corrosion, scaling, and a short life time. Although all of these shortcomings increase the maintenance cost and reduce the efficiency of GWHP systems, scaling has the greatest effect on reinjection.

In one GWHP project, PVC-U tubing from China was used instead of steel tubing in the production well (400 m) and the reinjection well (437 m). These two wells are located in the city of Zhengzhou in the Henan province. As this is the first time PVC-U tubing has been used for a completion well of such depth, there are no previous works to reference. One part of PVC-U tube well was cracked during the completion process of the reinjection well, but after the suitable technology was used to dispose of the cracked tube, it was completed successfully. The pumping well was completed without incident after learning from the accident during the reinjection well completion. Some key conclusions on PVC-U tube drilling and completion technology have been made as a result of this project.

2. CHARACTERISTICS OF PVC-U TUBE

PVC-U is short for high intensity polyvinyl chloride, its composed by PVC colophony, stabilization material, lubricant, palette, filling, machining assistant, after machine pinch and extrusion the PVC-U tube for water well are made. PVC-U tubing has the following characteristics: it is light weight and non-corrodible and has a slippery surface, energy-efficient production, and a larger coefficient of thermal expansion than that of steel tubing. Further, because of its large density (1400 kg/m^3), the use of PVC-U tubing can reduce the transport cost and work intensity. Normal steel tubing corrodes easily in wet surroundings and has a lifetime of only 5-10 years. On the other hand, PVC-U tubing is not affected by wet surroundings, ground water, or acid and alkali effects, and the estimated PVC-U tube lifetime is 50 years. Compared to steel, the production process of PVC-U tubing requires a lower temperature (90-110°C), and PVC-U tubing can be utilized in suitable areas according to the Energy Saver and Exhaust Reducer policy called for by the Chinese government. However, due to its large coefficient of thermal expansion, PVC-U tubing cannot be used if the surrounding temperature is higher than 60°C, and impact should be avoided in transport and completion processes.

3. DRILLING TECHNOLOGY OF PVC-U WELL

The drilling technology of wells using PVC-U tubing is similar to that of normal well drilling processes. The choice of the drilling method depends on the drill equipment and geological conditions. Compared to steel wells, PVC-U wells need larger space between the bore-hole and well casing. We recommend the space between bore-hole and well casing should be no less than 100 mm.

For this shallow geothermal development project, the designed depth of both wells were around 400 m. A Hongxing-400 drilling machine was used, as its maximum safe drilling depth is 600 m. A BW850/50 mud pump was used. The discharge pressure of this pump can be changed by adjusting the jar diameter and piston. A three-cone rock bit was used along with a drilling pipe of Φ 89 mm and a drill collar of Φ 178mm. The drilling process tool configuration is as follows (from bottom to top): three-cone rock bit, two Φ 178mm drill collars, Φ 89mm drill pipes, and the drive pipe. The operation regulations are large pump discharge, middle rotary speed, and low bit pressure. Two examples of PVC-U tube wells structure design are shown in Table 1.

Table 1: Two examples of PVC-U tube wells structure design

No.	depth(m)	hole structure	well casing structure
1	437	0 ~ 150m Φ450mm	0 ~ 150m Φ315×14.5mm
		150 ~ 437m Φ311mm	150 ~ 437m Φ160×8mm
2	400	0 ~ 150m Φ550mm	0 ~ 150m Φ315×15mm
		150 ~ 400m Φ450mm	150 ~ 400m Φ160×8.5mm

4. COMPLETION TECHNOLOGY OF PVC-U WELL

4.1 Preparation

After the drilling was finished, some reparation work needed to be done before the well was completed. This included a geophysical log, a PVC-U well tube check, making the wood centralizer, and mud control in the hole.

4.1.1 Geophysical Log

The geophysical log included spontaneous potential, grade of view resistivity, well deviation, and well depth. The position of the screen tube was decided according to the results of the geophysical log.

4.1.2 PVC-U Tube Checking

PVC-U well tubing has less impact resistance, so it is easy to cause damage during the transportation process (including loading and unloading) that cannot be detected by simple visual inspection. Damaged tubing cannot be put into a hole because it is very dangerous. To avoid this kind of situation, it was necessary to check each PVC-U tube before well completion. This was done by tapping the tube with a small hammer for auditory inspection. If the sound was not normal, the tube was damaged and was not put into the well.

All tubes were placed according to the order of completion technology most convenient to workers.

4.1.3 Wooden Centralizer

To ensure that the PVC-U tubing and the well had the same centre point and that the tube was vertical and gravel packing was uniform, wooden centralizers were needed. The suitable amount of wooden centralizers is 2-3 groups per 100 m, each group containing 3 centralizers. Figures 1 and 2 show the wooden centralizer and its fastening method, respectively.

Figure 1: Wooden centralizer

Figure 2: Wooden centralizer fasten method

4.1.4 Mud control

Because of the characteristics of PVC-U tubing, the density of mud in the hole was lowered as much as possible before completion work was undertaken. We recommend the density of mud in the well should be 1.05-1.10 g/cm^3 before PVC-U tube is put into the hole.

4.2 Completion Technology

4.2.1 PVC-U Tube Sinking

The sinking of PVC-U tubes depends on drill rig lifting. The tubes are connected by a screw thread. The bottom tube has a wooden guide and some 8-10 mm holes to keep the balance of mud between the in-tube and out-tube. Figure 3 shows the PVC-U plastic tube structure.

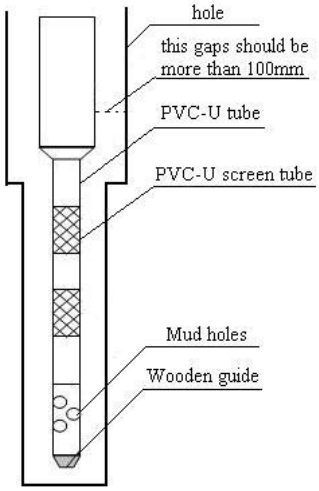

Figure 3: Sketch map of PVC-U well tube.

Ideally, the tube should sink slowly. During the tube sinking process, the pump and recharge tube should be prepared, and one person should observe the mud level. When the mud level between in-tube and out-tube is more than 10 m, the mud in the tube or hole should be recharged immediately; otherwise, the PVC-U tube may crack. Application of soapy water may help the PVC-U tube connect more easily. A photograph of the PVC-U tube sinking process is displayed in Figure 4.

Figure 4: Photograph of PVC-U Tube Sinking Process

4.2.2 First Bottoms-up and Mud Exchange

When the PVC-U well tubes have sunk successfully, the first bottoms-up and mud exchange should be performed immediately. After the mud circulates regularly, test the mud density and viscosity immediately. When the density is 1.05-1.1 g/cm^3 and the viscosity is 18-20 s, that indicates that this stage of the process is complete.

4.2.3 Gravel Packing and Shut-off of Water

The dynamic water method should be used during the gravel packing process, as the mud circulates, and the mud pump cannot be stopped during the process.

Because the speed of gravel packing should be slow, normally one person should shovel the gravel into the well for the safety of the PVC-U tubes. If the gravel packing occurs too quickly, the gravel may strike the PVC-U tubing frequently, assemble in one place, and collapse suddenly, possibly damaging the tubing.

Shut-off water use the high quantity clay balls, the diameter should be less than 30 mm, and keep half air-dry state. The speed of shut-off water should be lower, mass clay balls and without air-dry clay balls put into well is forbidden.

4.2.4 Second Bottoms-up and mud exchange

Clean water should be used for the second bottoms-up and mud exchange. If the sands and solids cannot easily be removed, use mud with a viscosity around 20 s to make bringing the bottom up possible.

4.2.5 Well Cementation

The aim of well cementation is to fix the position of the well, balance the pressure of the formation, and prolong the lift time of the well. Well cementation calls for the use of 5-8 mm architecture detritus. The amount of detritus should be in accordance with theoretical calculations.

4.2.6 Well Flushing

For PVC-U tube well, we recommend the air compressor or dive pump well flushing method. A large dewatering depth is forbidden. During the well flushing, the liquid surface cannot drop more than 70 m.

5. SAFETY ANALYSIS OF PVC-U TUBE USE AS WATER-SUPPLY WELL TUBE

5.1 PVC-U Tube Loading Condition Analysis

The ideal conditions of loading PVC-U tubing into a well are very complex. The loading conditions are different depending on what completion steps are used.

The axial tension and external pressure are the main factors in the analysis and design of PVC-U tube loading. The load of PVC-U tube design should be in the most dangerous situation. PVC-U tubing is lightweight and has a high buoyancy, so the axial tension is very small. Wells with depths is lower than 800m can not consider the axial tension, but the pressure and the safety control measure is necessary.

5.2 Effect of Liquid Surface Difference between In-tube and Out-tube on PVC-U Tube Loading Conditions

The effect of the liquid surface difference between in-tube and out-tube on PVC-U tube load condition can be calculated according to Equation 1

$$P = \left(H\rho_1 - h\rho_2\right)g \qquad (1)$$

where P, H, h, ρ_1, ρ_2, and g are the well tube pressure caused by liquid surface difference, liquid surface height in the out-tube, liquid surface height in the in-tube, liquid density in the out-tube, liquid density in the in-tube, and gravitational acceleration, respectively.

The PVC-U tube loading conditions were calculated for each well. Figure 5 shows how PVC-U tube pressure varies with the liquid surface height in the in-tube.

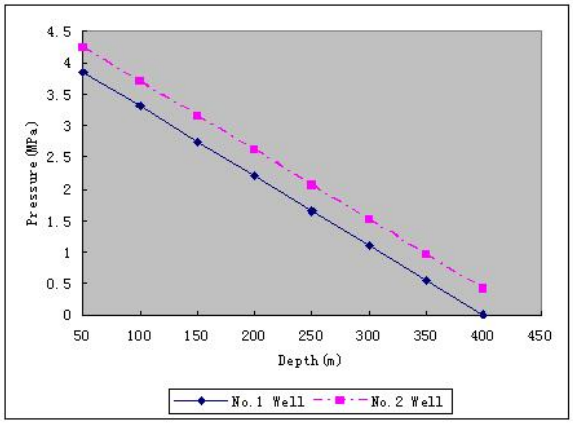

Figure 5: Pressure of PVC-U tube at different liquid surface heights in the in-tube.

5.3 Rock Affect on PVC-U Tube Load Condition

Clay layers have a lateral pressure because of deformation. During the well flushing and water pumping process, the water level in the tube decreases. This part of well tube will experience the lateral pressure of the clay layer, and negative pressure will appear in the tube, with the maximum pressure at the bottom. This kind of pressure can be calculated using Equation 2

$$P = \sum\left[u/(1-u)\right]g\rho H \qquad (2)$$

where P, u, ρ, g, H are the pressure of the clay layer on the ektexine of the PVC-U tube, lateral pressure coefficient, density of clay, gravitational acceleration, and depth of calculated well tube section, respectively.

For general water supply wells and PVC-U tube wells, the tubing has already been surrounded by gravel when the well flushing and water pumping process occurs, so the tubing does not have contact with the earth. Thus, the pressure is calculated using the lateral pressure coefficient of sand (0.4) and density of gravel (1.75g/cm^3) with a resulting pressure of 1.17×10^4·H Pa. Table 2 shows how the rock affected pressure of PVC-U tube varies with water depth.

Table 2: Rock Affected Pressure of PVC-U tube in different water leavel depth

H(m)	P(MPa)	H(m)	P(MPa)
10	0.117	60	0.702
20	0.234	70	0.819
30	0.351	80	0.936
40	0.468	90	1.053
50	0.585	100	1.17

5.4 PVC-U tube Safety Analyze

According to calculation and analysis, the most dangerous processes when using PVC-U tubing are PVC-U tube sinking, gravel packing, well flushing and water pumping. The safety measures for completion technology derived from theory, research, and the characteristics of PVC-U tubing include reducing the pressure difference between the in-tube and out-tube as much as possible, avoiding impact on the PVC-U tube. If we can control completion technology and standardize the technology regulations, the maximum depth of PVC-U tube wells may reach at least 500 m. While pumping water, the liquid surface cannot drop more than 70 m.

6. CONCLUSION

This paper introduces drilling and completion technology for wells using PVC-U plastic tubing. The two eyes of the PVC-U wells are the deepest domestic currently, and resolve the problems such as tube sinking difficult in PVC-U tube well completion.

The key conclusions made concerning the drilling and completion of PVC-U tube wells are as follows. (1) The well structure design should be reasonable, and the gaps between the well and tubes should be more than 100 mm. (2) A PVC-U tube check is necessary before tube sinking, and damaged tubes should not be sunk into the well, as this may cause the tube to be cracked in the well. (3) PVC-U tube sinking is a key step in well completion, and the “balance pressure” tube sinking method can ensure the safety of the PVC-U tube. (4) In the tube sinking and well flushing processes, the liquid surface cannot drop more than 70 m.

PVC-U tube is a new kind of well tube material that can prolong the lifetime of wells, improve the quality of wells, and reduce the working intensity because of the material’s light weight. It is worthwhile to popularize the use of PVC-U well tubing and its technology in this country.

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