VERTICAL U-SHAPED HEAT EXCHANGERS FOR CONSTRUCTION ENGINEERING
New Promises and Future Challenges

by

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The ground source heat pump system is a promising technology for building heating and cooling by using underground energy, however, many technical problems, e. g. low energy utilization rate and inefficiency operation, have greatly hindered its wide applications. This paper studies the key technologies of vertical U-shaped heat exchangers in construction engineering to solve the bottleneck problem and optimizes the system. Three commonly used backfill methods are analyzed, and a double U-shaped branch pipe is recommended to improve construction efficiency. The paper sheds a bright light on green energy utilization with high-efficiency, energy-saving, and environmental protection.

Key words: *ground source heat pump, vertical U-shaped pipe, backfill method, construction key technology, pipe fittings optimization*

Introduction

Under the dual pressure of the global shortage of renewable resources and the deteriorating environmental pollution, it has become an urgent problem to develop green and renewable energy for environmental protection. In order to alleviate the above crisis, the ground source heat pump air conditioning system emerges at the right moment. The publishing of China's first geothermal development five-year plan, the geothermal energy development and utilization of the *13th Five-Year* plan, sheds a bright light on geothermal energy research.

The ground source heat pump system is a comprehensive technology for building heating and cooling by using low-grade energy stored in underground rock and soil. Because of its high-efficiency, energy-saving, environmental protection and renewable energy utilization technology [1, 2], it is called as *the green air conditioning*.

With the rapid development of the technology, the ground source heat pumps have found wide applications in agriculture, industrial waste heat, and subway waste heat. As we all know, there are many factors that affect the efficient operation of soil-source heat pump systems, such as well depth [3], well spacing [4], well layout [5], and soil temperature recovery [6].

In order to improve the energy utilization rate and the operating efficiency of the ground source heat pump system, Li *et al.* [7] and Emmi *et al.* [8], respectively, studied the

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operation strategy of the ground source heat pump and the solar-soil source composite system. Spitle *et al.* [9] and Noorollahi *et al.* [10] reviewed the thermal response test technology and the parameters of the buried tube heat exchanger, respectively. The construction of a ground-source heat pump is a prerequisite for the efficient and stable operation of the system, but no research has been reported in construction.

At present, the high initial investment is one of the factors preventing the further promotion of ground source heat pump systems. Among all funds, construction costs account for a relatively large amount. Improving construction efficiency can save initial investment costs. Reasonable and standardized construction methods can not only reduce investment costs but also ensure the efficient and stable operation of the ground-source heat pump system. Therefore, this paper proposes several methods in construction technology and improves the pipe fittings of the ground source heat exchanger to improve the construction efficiency, to reduce the investment cost and to realize the enhancement of the ground source heat exchange capacity.

Key technology for the buried pipe construction

The soil source heat pump system mainly includes a buried pipe heat transfer system, a heat pump unit system, an indoor device system. The heat transfer system of the buried pipe is a geothermal energy exchange system with heat exchange between the heat exchanger and the underground soil. Tracking and researching the key construction technology of vertical U-type ground pipe of the ground source heat pump is of great significance for improving construction efficiency and quality, ensuring stable and efficient operation of the system.

Before drilling, it is necessary to accurately locate the release line, determine the boundary line of the borehole area, the number of boreholes, the location of the borehole and the spacing of the boreholes, the deviation should be controlled within 10 cm.

A certain distance between the buried pipes can not only avoid heat interference but also reduce the power consumption of the building [11]. According to the research, the tube spacing is generally 3~6 m. Taking into account other factors, 4 m might be the best spacing, and sequential arrangement is more conducive to the recovery of soil temperature than the cross arrangement, providing a highly efficient and stable source of heat for the heat pump system. However, Bi simulated a single U-shaped heat exchanger, and found that the heat action radius of drill pipe is 1.9 m [12]. In order to avoid the overflow of wastewater and muddy water on the construction ground which might result in blurring or covering of the positioning line, a long-term and unbroken positioning line should be set.

During the drilling procedure, we should check the position of the drilling machine at any time and check the perpendicularity of the drill pipe to ensure that its horizontal deviation is no more than 1% and the vertical deviation of the drill pipe is no more than 0.5%, so as to avoid damage. In the upper lose stratigraphic drilling, we should follow the principle of low pressure and slow speed to prevent a large amount of viscous mud drilling [13]. The depth of well generally exceeds the designed depth of 1~2 m to ensure that the actual buried depth of the pipe reaches the design requirements. The drilling area of the borehole layout rules can be set up between the two rows of boreholes, as a water circulation carrier for drilling work, such as the mud pool shown in fig. 1. When using natural backfill, select 10 boreholes as a circulation loop shown in fig. 2. Pumping water from the mud pool for drilling, after circulating mud passes through the finished well, it is then remitted into the mud tank, and the mud is naturally precipitated in the well for backfill.

Figure 1. Mud pools between boreholes

Figure 2. Circulation loop between boreholes

The vertical U-shaped buried pipe should strictly follow the design and construction specifications when it installs. The buried depth affects directly the heat exchange and ensures that the pipe depth meets the design requirements. It is a prerequisite for satisfying the construction load requirements and efficient system operation. Before the pipe install, it shall be confirmed that there is no big hard substance in the wellbore, no collapse and no damage to the buried pipe, and the U-shaped buried pipe joint is well protected. Post injection pressure, the stable pressure should be kept for at least 15 minutes, the pressure drop is not more than 3% and no leakage. In addition, underground pipe laying construction technology should also meet the following points:

- After the completion of drilling, the hole should be washed to prevent the settling of rock and soil powder formed in the drilling, and the effective depth of the hole should be considered to ensure that the lower pipe length meets the design requirements.
- Before the pipe goes down the well, the existence of rock debris, mud, sediment and water in the wellbore results in large buoyancy and resistance in the wellbore, which makes the downpipe difficult. Therefore, when the pipe is down, it will be filled with water. The unfavorable factors can be overcome by using the buried pipe and the pressurized water. If necessary, the precast concrete guide can be used to increase the buried pipe's weight or to drill down the well with the drill pipe to increase the downpipe speed.
- The interval of the vertical U-shaped buried pipes should be 3~4 m [14], so that the U-shaped pipe buried in the various branches is in a separate state to avoid heat bridge effect and to ensure U-shaped pipe heat transfer.
- After the completion of the downhole operation of the buried pipe, the special end cap is used to seal the branch ports of the buried pipes, and the debris is strictly forbidden to enter the pipe hole, so as to prevent the blockage of the pipeline from occurring, and enhance the protection of the finished products which ensures the effectiveness of the construction work.

The backfill material between the heat exchanger and the whole wall is to enhance heat exchange of the buried pipe and soil, prevent water penetration, protect groundwater from the aquifer between contamination and the cross-contamination of materials. Backfill is a key link in the construction of the buried pipe. Choosing the right backfill material and backfill method is very important for ensuring the efficient operation of the ground source heat pump system. The role of backfill materials is mainly reflected in the following points:

- To heat the conduction medium. Backfill material is the heat transfer medium between the borehole and the pipe, and the thermal conductivity of the backpacking is an important index to measure the heat transfer effect of the buried pipe heat exchanger. The return packing of a high heat transfer coefficient can reduce drilling depth and reduce the system investment.
- To make the sealing hole dense. When backfilling a borehole, the backfill material should have the ability to prevent penetration of surface water through the borehole into the ground which results in contamination of groundwater and cross-contamination of aquifers. Meanwhile, ensure the density of sealing, prevent hole and disconnection in borehole so as to avoid the heat transfer effect of the buried tube heat exchanger.
- To expand and consolidate. After the vertical U-shaped underground pipe is completed, the U-shaped buried pipe, the backfill material and the inner wall of the borehole are well combined to select the intumescent material with good expansibility and adhesion to avoid the pipe shrinkage caused by the shrinkage of the backfill material the gap between the wall and the backfill material to reduce the contact resistance to ensure that the heat pipe buried effect [15].

The thermal conductivity of the backfill material with high thermal conductivity can reach 3.3 W/mK and the maximum drilling depth can be reduced by 22~37% [16]. However, the backfill material with larger thermal conductivity will easily cause the thermal bridge effect between branch pipes to increase. The study found that considering the construction difficulty and economy, the best backfill material is that the thermal conductivity is slightly higher than the soil around the pipe [17]. At the same time, the addition of PCM can reduce the fluctuation of soil heat improve heat pump performance [18]. It is of great significance to select the best backfill materials according to the characteristics of the soil thermal properties in different areas, which is of great importance to the efficient operation of the guarantee system and the reduction of the cost of investment.

Through theoretical analysis and practical project verification, it is the best way to backfill by injecting the backfill material into the bottom of the borehole to displace the liquid in the borehole and pumping backfill the mud [19]. The paper analyzes three kinds of backfill methods, compares their advantages and disadvantages as shown in the tab. 1, which provides references for the selection of backfill methods for actual projects.

Table 1. Comparison of three backfill methods

Backfill method	Advantage	Disadvantages
Natural backfill	Low cost and no additional backfill material. Backfill convenience, high construction efficiency.	Because of the difference in the geological strata, the thermal properties of the strata are not obtained. Heat transfer performance is not guaranteed
Replacement backfill	The backfill is dense. The air gap and air gap in the backfill process are improved, and the heat transfer efficiency is more reliable.	Need to be equipped with high pressure backfill equipment and pipelines. The equipment is not easy to clean and the pipe is wasted seriously. A large amount of backfill engineering.
Artificial backfill	Backfill without equipment, simple operation.	From top to bottom backfill, easy to appear blockage, gas hole, tower bridge, and other defects, backfill the compactness is not guaranteed.

The natural backfill is also called as the backfill of the original pulp. After completing the drilling and down-hole operation, during the drilling process of adjacent boreholes, the circulating mud is flowing through the perforated well, and the mud is naturally precipitated to the bottom of the well bottom, replacing the backfill from bottom to top, as shown in fig. 3. The backfill method precipitation uniform will not pressure buried tube backfill dense and the density is more ideal [20].

- The replacement backfill is the mud water and air in the replacement borehole at the bottom of the good hole by the high pressure backfilling pump and the transmission conduit. To ensure that backfilling has no void and no cavitation, and when the backfilling is returned to the top of the hole, the mud density is equal to the density of the grouting mud. The principle of backfill is shown in fig. 4. Replacement backfill can intuitively judge whether the backfill is sufficient, but the requirements for the equipment are high, and the waste of the pipe is easily caused.
- The artificial backfill is to fill the backfill slowly and evenly into the bottom of the borehole from the hole and to inject water intermittently into the hole. Due to a large amount of air and mud in the borehole, it is not easy to achieve a single backfill. Generally, the artificial backfill should be performed after the first backfill is completed.

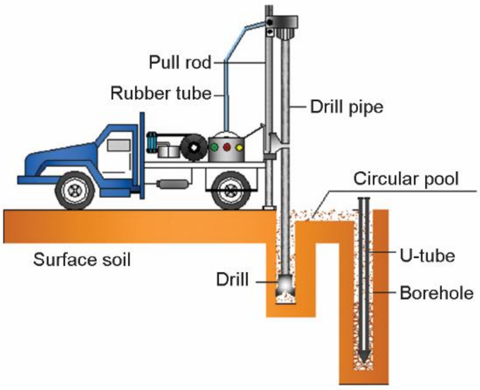


Figure 3. Natural backfill schematic

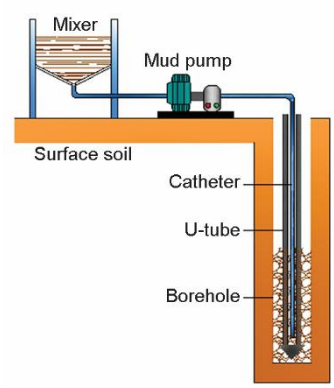


Figure 4. Replacement backfills schematic

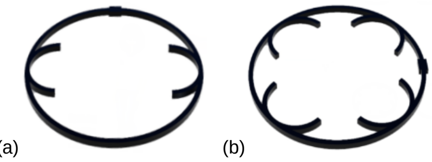
After the completion of all vertical U-type buried pipes, the laying work of the horizontal pipe is carried out. To the construction site leveling in the first place, according to construction drawing of horizontal tube position location pay-off, trench excavation, support embedded, horizontal buried pipe laying, vertical and horizontal buried pipe buried pipes connection and system pressure testing and flushing, covered in trench backfill. Horizontal header laying, the bottom of the trench laying diameter equivalent to the thickness of the sand [21], the tube filled with water pressure test, pipe welding and other requirements in line with the ground source heat pump system engineering specifications (GB50336-2005) requirements, backfill soil Layer tamping, the top of the tube within 0.5 m of the backfill using manual compaction, other parts can be mechanical compaction.

The vertical buried pipe and horizontal buried pipe installation and backfill belong to the underground concealment project, so it is difficult to detect the quality and density of backfill. Therefore, in order to improve the quality of backfill construction, the heat exchange effect of the buried pipe heat exchanger, and the strict control of the technical requirements of the backfill process, the heat exchange performance of buried pipe heat exchanger is of great significance.

Problems and improvement measures in construction

The research shows that the rational use of spacer rings can reduce the thermal heat interference and reduce the drilling length by 5~10%, which obviously reduces the system investment and operating costs [22]. The commonly used pipe engineering is easy to form a transverse barrier, and there is cavitation backfill compaction, which affects backfill density, increases the thermal resistance and reduces the heat transfer efficiency of the buried pipe heat exchanger. There are many theoretical researches on reducing thermal short circuit [23], but the practical application is still to be improved.

To solve this problem, this paper proposes a new vertical U-tube pipe spacer ring, and its structure is shown in fig. 5. The spacer ring uses hard materials and an external corrosion protective layer of PE composites. There are two forms with single-U-tube and double-U-tube, respectively. The diameter of the ring and the inner diameter of the groove can be matched according to the hole and the diameter of the branch pipe. The utility model has the advantages of simple and quick operation, large structural rigidity, good stability, and small cross-sectional area and the like, which can ensure the spacing between the branches and prevent the blockage in the backfill during the backfill process, and improve the transmission of the ground tube heat exchanger thermal efficiency.



(a) (b)

Figure 5. Single U-tube pipe spacer ring (a) and double U-tube pipe spacer ring (b)

The commonly used prefabricated vertical double U-buried pipe can be considered as a combination of two single U-buried pipes. As shown in fig. 6, which are connected in parallel with the horizontal pipe. It is not easy to distinguish the branches of single U-shaped tubes when prefabricated double U-type buried pipe and horizontal pipe connection. If the connection error occurs, serious consequences will be caused. There are two commonly used methods to identify the branches of each single U-tube in the construction. One is to water a branch pipe in the four branches, the outlet branch and the water injection branch pipe are a single U-type pipe, and the remaining two branches are another single U-type pipe. The other is to one of the four branch pipe blowing. The water branch and blowing branch pipe is a single U-shaped pipe passage, the other two branch pipe is a single U-shaped pipe passage. The aforementioned two methods bring a tedious workload to the construction and affect construction efficiency to a certain extent.

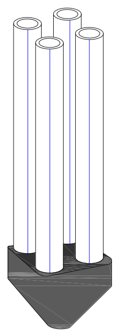


Figure 6. Traditional double U-type buried pipe

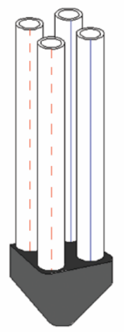


Figure 7. New double U-type buried pipe

According to the problems in the aforementioned construction process, this paper optimizes the design of a double U-shaped buried pipe. As shown in fig. 7, the two sides of the four branches are set up with two color lines. One of the two branches, a single U-way is set to the same color line (such as blue). The other two branches of the single U-channel are obviously different from the previous one (such as red). In this way, it is convenient to select the branch pipes connected with the horizontal pipe, which reduces the cumbersome task of distinguishing branch pipes and effectively improves the work efficiency.

Engineering commonly used ground tube heat exchanger has square and circular two forms of the tip shown in fig. 8. The shape of the tip has a direct effect on the velocity of sinking into the well. When the borehole diameter and the pressurized water have the same weight in the pipe, the liquid buoyancy in the borehole directly influences the lower well velocity of the buried pipe. When the hole diameter is certain, the larger the cross-section of the end head is, the larger the buoyancy will be, the smaller the drainage area will be, which is not conducive to the discharge of the lower liquid, thus causing the difficulty of the buried pipe.

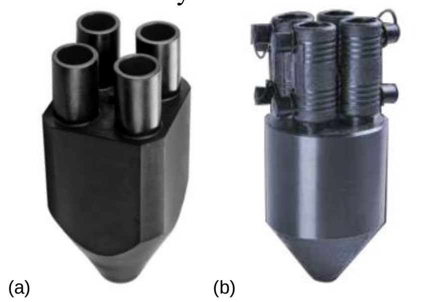


Figure 8. Double U-shaped square end (a) and double U-shaped round end (b)

Through the comparative analysis of the tab. 2, when the maximum cross-section size of the two ends is the same, the drainage area of the circular ends is 17.17% less than the drainage area of the square ends. It is concluded that the resistance of the square tube under the square end is smaller than that of the circular end, which is more conducive to the liquid discharge from the lower part of the end of the well. In order to improve the speed of the underground pipe, the U-type buried tube heat exchanger with the square end is recommended.

Table 2. Square and round end parameters for comparison

Tip shape	Maximum section size	Cross-section area of well hole	End cross-sectional area	Tip area accounted	Drainage area occupation ratio
Square	$L = 0.11$ m	0.0201 m^2	0.0061 m^2	30.09%	69.91%
Round	$R = 0.11$ m		0.0095 m^2	47.26%	52.74%

Conclusions

Through tracking and research on the key technologies for the construction of the ground-source heat pump underground heat exchange system, taking into account the goals of improving construction efficiency, reducing construction costs, and strengthening heat transfer, a reasonable solution and optimization plan for the problems existing in the construction is proposed.

The advantages and disadvantages of the three different backfill methods are compared. The appropriate backfill method based on the principle of adjusting to local conditions has important guiding significance for actual engineering. A U-tube pipe clamp is designed to improve the construction efficiency of the underground heat exchanger, reduce the degree of thermal short circuit between the branches, and strengthen the heat exchange capacity. The tube structure of the underground heat exchanger is optimized, which helps to identify the branch pipe passage and quickly connect the horizontal pipe. Therefore, construction efficiency is improved. In the same section of the wellbore, by comparing the drainage area of the square end and the round end, it was found that when the cross-section length of the two ends is the same, the drainage area of the round end is 17.17% smaller than the square end. In view of this, the square end has advantages in construction efficiency.

Through the previous research, the purpose is to improve the construction efficiency of the underground heat exchange system, reduce the initial investment, and strengthen the heat exchange capacity on the premise of ensuring the construction quality. However, there are still many shortcomings in the actual construction of the ground source heat pump system. For example, during the construction process, the drilling machine is prone to failure, the drill pipe and the drill are easy to fall off, the maintenance and repair of the drill pipe and drill take a long time. Strengthening the research and development of shallow soil source heat pump drilling equipment is of great significance to improve the drilling efficiency and ensure the quality of the construction. Borehole backfill less mechanical pumping backfill, the main reason is that the equipment is expensive, and the delivery pipe is relatively thin and needs to bear high pressure, which requires high equipment. The backfill is easily bonded to the inner wall of the pipeline, so it is not easy to clean, which restricts the application of the backfill method. Therefore, the research and development of mixed material and pump, convenient cleaning, stable and reliable backfill equipment need to be solved.

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