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Thermal Test and Modeling Analysis of Buried Pipe Borehole with Barite Powder Backfill

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ABSTRACT:

In order to study the effect of backpacking containing barite powder on the heat transfer efficiency of buried pipe borehole in mountainous and plain areas of Beijing, comparative analysis of laboratory experiments and field thermal response experiments were carried out. The quaternary boreholes in plain area were backfilled with medium sand and the bedrock boreholes in mountainous area were backfilled with cement mortar. Laboratory experiments showed that the thermal conductivity of medium sand backfill increased gradually with the increase of barite powder content, and the thermal conductivity increased by 0.037 W/m·K for every 1% increase of barite powder content from 1% to 10%. When the specific gravity of barite powder was 5%, the thermal conductivity of medium sand backfill samples was increased by about 14%. When 5% barite powder was added to cement mortar, the thermal conductivity was increased from 1.76W /m·K to 1.89W /m·K with an improvement ratio of 7.3%. According to the field thermal response test results, under summer conditions in the same site, the heat transfer rate of backfilling borehole containing barite powder increased by 2.4W/m and 3.5% per meter compared with that of medium-sand backfilling borehole in plain area. The heat transfer rate of cement mortar backfill containing barite powder was increased by 2.7W/m and 3.9% per meter. The numerical simulation model of quaternary system and bedrock area was established. It was found that the content of barite powder was increased to 10% and the heat transfer rate of boreholes was increased by about 6.5%. In general, the heat transfer capacity of buried pipe is improved and its sustainability is better after adding barite powder.

1. INTRODUCTION

The improvement of the ground layer heat transfer capacity helps to enhance the buried pipe heat transfer capacity. In order to improve the performance of borehole backfill, scholars at home and abroad study the shape and placement of buried pipes, among which the ground layer backfill is one of the important ways to improve the thermal conductivity of boreholes (Wan,2020; Yang 2021; Nan et al.,2017; Yongying et al.,2022).

There are a variety of backfill materials, and scholars have conducted research (Youtang et al.,2019; Xianyue et al.,2019). In recent years, the proportioning substances and testing methods to improve the backfill of buried pipes have diversified, and new materials and means have emerged. Materials such as bentonite(GB 50366-2009), cement(Ziyuan et al.,2022;), fly ash(Weicui et al.,2006;), quartz sand(Charles,1999), graphite(Charles,1999), and earth-sand mixture (Xu and Xiaobing,2004)have been added to the backfill proportioning studies. Barite chemical composition is barium sulfate ($BaSO_4$), barite Mo-style hardness of 3~3.5, specific gravity (4.2~4.7), low hardness, brittle, barite chemically stable, insoluble in water, acid, alkali and organic intermediates, non-magnetic and toxic.

Research methods from experimental research, numerical simulation and other ways. The author previously conducted a test study on the thermal conductivity of barite powder added to medium sand backpacking in the laboratory. The study found that under the condition of saturation, the thermal conductivity of the backpacking gradually increased with the increase of the content of barite powder (Ningbo et al.,2018; Zilong et al.,2020). Therefore, it is speculated that barite powder can be added to the borehole backpacking.

The backpacking containing barite powder can improve the heat transfer capacity of the backpacking (medium sand) in laboratory tests. In the actual field heat transfer, does the heat transfer capacity of buried pipe lift the stratum as obtained by laboratory test due to the addition of backfill containing barite powder? Further, whether there is a difference between plain areas and mountain area remains to be studied. The plain area means that the thickness of the quaternary system is greater than that of the borehole. The Quaternary system in mountainous areas is thin and mainly composed of rock strata. This paper shows the contribution of backpacking containing barite powder to improving the heat transfer capacity of borehole by comparing the results of indoor tests and field tests and numerical simulation.

2. THERMAL CONDUCTIVITY TEST OF BACKFILL CONTAINING BARITE POWDER

2.1 Sample collection and preparation

Medium sand backfill was collected from the buried pipe ground source heat pump demonstration project site in Xiji Town, Tongzhou District of Beijing. 10 different specific gravity of barite were mixed with 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, and 10% by weight, respectively, and the barite particle size was 200 mesh. Together with the sample of medium sand without barite powder, a total of 11 water-saturated samples were made.

Two medium sand samples were collected from two boreholes in Tongzhou sub-center of Beijing. TF-1 and TC-1 were prepared after the sand backpacking sample was saturated with water. Barite powder with a specific gravity of 5% was added to the TF-1 sample and barite powder with a specific gravity of 50% was added to the TC-1 sample to make two saturated samples, TF-2 and TC-2 respectively.

Two samples of medium sand were collected at each of the two boreholes in Tongzhou sub-center of Beijing. The mid-sand backfill samples were made into TF-1 and TC-1 after being full of water, and barite powder with a specific gravity of 5% was added to the TF-1 sample, and barite powder with a specific gravity of 50% was added to the TC-1 sample to make two full-water samples, TF-2 and TC-2, respectively.

The bentonite cement mortar backfill was made by collecting medium sand backfill from Nancha Village, Pinggu District and proportioning it. The ratio of cement mortar was 3:1:0.5 for sand: cement: bentonite. 5% barite was mixed to make cement mortar and two water-filled samples are PN-1 and PN-2.

2.2 Sample Testing

The Hotdisk thermal constant analyzer was used to test the thermal conductivity of medium sand backfill with different specific gravity of barite powder. The Hotdisk TPS 2500s is a thermal constant analyzer that uses the transient planar heat source method to test the thermal properties of geotechnical samples (Figure 1). The transient planar heat source method is based on the principle of planar one-dimensional non-stationary thermal conductivity: the planar heat source in an infinite medium is subjected to an instantaneous heating pulse in the initial thermal equilibrium state to produce a dynamic temperature field inside the medium, and the thermal conductivity and thermal diffusivity of the sample are calculated by fitting a function curve using the temperature data generated by the heat conduction process (ISO 22007-2-2008,2015). The sample to be tested was prepared as a cylinder with a flat surface and tested using a probe of model 2501 (Figure 2).

The test temperature was 20°C at room temperature, the test time was 40s, and the test power was 200mW. 17samples were tested. Among them, 15 samples were from plain area, 2 samples were from mountain area, and the test results are shown in Table 1.

Figure 1: Thermal constant analyzer **Figure 2: Thermal constant probe**

Table 1: Heat conductivity text results of backpacking containing barite powder

Sample number	Lithology (Sample preparation, Water-saturated conditions)	Thermal conductivity (W/m·K)	Collection and backfilling sites
TX-1	Medium sand backfill 1#	1.3107	Plain : Xiji Town , Tongzhou District
TX-2	Medium sand backfill containing 1% barite powder	1.3313	
TX-3	Medium sand backfill containing 2% barite powder	1.3777	
TX-4	Medium sand backfill containing 3% barite powder	1.4360	
TX-5	Medium sand backfill containing 4% barite powder	1.4673	
TX-6	Medium sand backfill containing 5% barite powder	1.4980	
TX-7	Medium sand backfill containing 6% barite powder	1.5437	
TX-8	Medium sand backfill containing 7% barite powde	1.5530	
TX-9	Medium sand backfill containing 8% barite powder	1.6097	
TX-10	Medium sand backfill containing 9% barite powder	1.6410	
TX-11	Medium sand backfill containing 10% barite powder	1.6673	
TF-1	Medium sand backfill 2#	1.8107	Plain : Sub-centre , Tongzhou District
TF-2	Medium sand backfill containing 5% barite powder	2.0547	
TC-1	Medium sand backfill 3#	1.5837	
TC-2	Medium sand backfill containing 50% barite powder	2.1190	
PN-1	Cement mortar(Water-saturated and soft conditions)	1.7630	Mountainous area: Pinggu District
PN-2	Cement mortar containing 5% barite powder	1.8917	

2.3 Analysis of Sample Test Results

According to the indoor sample thermal conductivity test, every 1% increase of barite powder in the 1# medium sand backpacking, the thermal conductivity of the backpacking increases by about 0.037W /m·K. When the proportion of barite powder is 5%, the thermal conductivity increases by 0.18W/m·K, and the proportion increases by 14.3%. When the content of barite powder reached 10%, the thermal conductivity increased by 0.37W/m·K compared with the medium sand backpacking without barite powder, and the lifting ratio increased to 27.2%.

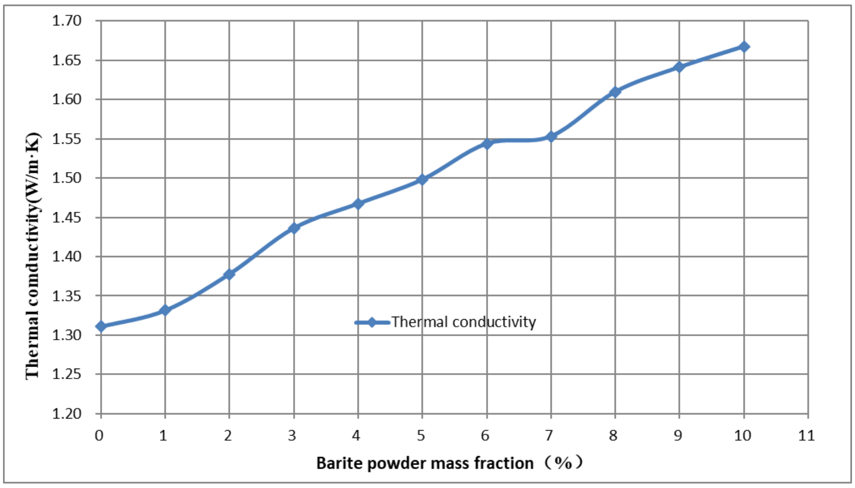


Figure 3: Heat conductivity change with specific gravity increase of barite powder

When the proportion of barite powder is increased to 5%, the thermal conductivity increases from 1.81 W/m·K to 2.05 W/m·K, increasing by 0.24 W/m·K and increasing by 13.5%.

When the proportion of barite powder is increased to 50%, the thermal conductivity increases from 1.58W /m·K to 2.12W /m·K, increasing by 0.54W /m·K and 33.8%.

The thermal conductivity of the backpacking increases with the increase of the content of barite powder. The initial thermal conductivity of different sand backpacking is different, and the thermal conductivity system is improved slightly after adding barite powder. In general, when the proportion of barite powder is 5%, the thermal conductivity increases by about 14%; when the proportion of barite powder is less than 10%, the thermal conductivity increases steadily, about twice as much as that of 5%. At 10%~50% percent, the thermal conductivity increases slowly.

After adding 5% barite powder to cement mortar, the thermal conductivity increases from 1.76 W/m·K to 1.89 W/m·K, increasing by 0.13 W/m·K and increasing by 7.3%. Compared with medium sand, the lifting ratio of cement mortar with barite powder is lower than that of medium sand backpacking (Figure 4).

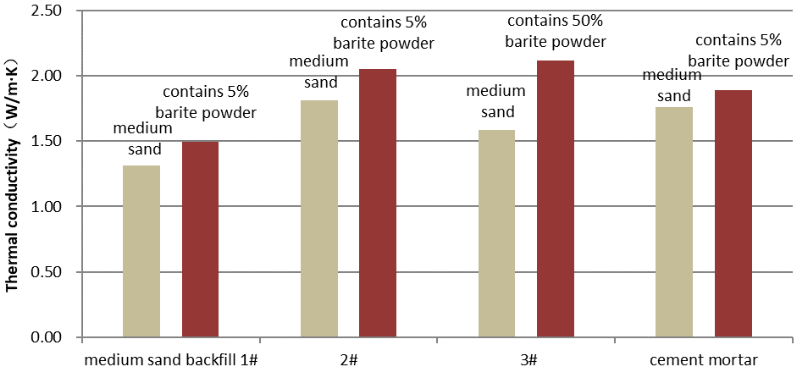


Figure 4: Heat conductivity chart column

3. IN-SITU HEAT TRANSFER TESTS ON BURIED PIPES CONTAINING BARITE POWDER BACKFILL

Field thermal response tests were carried out in backfill boreholes containing barite powder, and field measurements of heat transfer capacity of backfill boreholes containing barite powder were obtained.

3.1 In-situ Heat Transfer Tests

In the same engineering block, the sand backfill and the backfill containing barite powder were backfilled into the borehole to carry out the field heat transfer test. The HDPE pipe was drilled into the drilled hole and backfilled with different mixed backfillers to complete the hole formation of the thermal response test hole (Figure 5). After the backfill is completed, it is necessary to conduct a pressure test again, pressure 0.6~1.2MPa, with pressure observation for more than 2 hours, no seepage, no leakage, no rupture, and the pressure drop does not exceed 0.05MPa is qualified.

Figure 5: Drill hole site backfill map

An on-site thermal response test is conducted after the heat exchange hole construction is completed, and one group of on-site thermal response test is carried out for each hole to obtain parameters, such as the initial temperature of the ground, heat exchange of a single hole, and average thermal conductivity of the ground. The principle of thermal response test is that the water circulation part of the tester is connected to the buried pipe heat exchanger to be tested, forming a closed loop, and the liquid in the loop is continuously circulated through the micro-circulation pump inside the instrument, so that the tester can provide an energy-stable and adjustable heat source, and the heat provided is released to the buried pipe heat exchanger through the circulating water in the water system and finally released to the earth (Figure 6). During operation, the tester records parameters such as inlet and outlet water temperature, circulating water flow rate, and heating power of the buried pipe heat exchanger. The thermal response test equipment was used to determine the heat transfer capacity of the buried pipe heat exchanger under stable winter and summer operating conditions, thus determining the heat transfer capacity per linear meter of the buried pipe heat exchanger. The thermal response test temperature was stabilized at 35°C for summer operating conditions and 5°C for winter operating conditions of the water supply. The heating power of the stable heat flow thermal response test is 6KW and 9KW respectively, and the average thermal conductivity of the ground layer is obtained after calculation. The duration of the thermal response test is not less than 48 hours, and the circulation flow rate is not less than 0.8m^3/h.

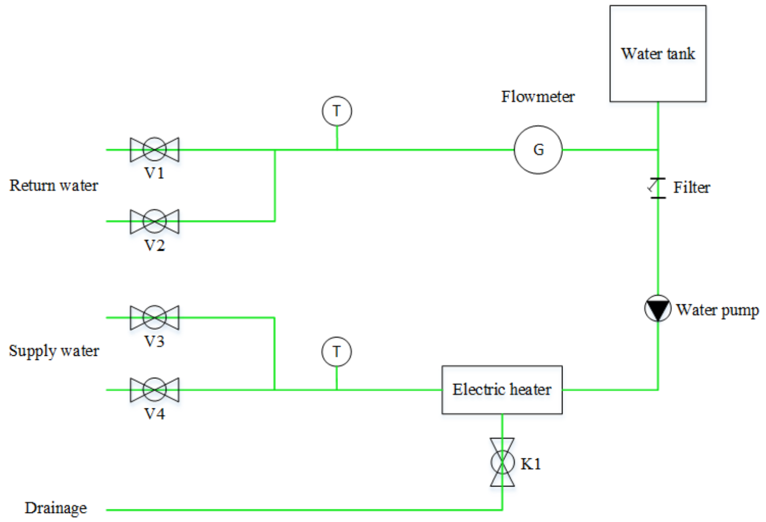


Figure 6: Schematic diagram of tester circulation system

3.2 Measured Results

The average thermal conductivity of the A5 medium-sand backfill borehole in Xiji Town, Tongzhou District, is 2.17 W/m·K. Under stable working condition, the heat exchange rate per meter in summer is 69.65 W/m, and that of extended meters in winter is 42.46 W/m. The average thermal conductivity of the A7 medium-sand backfill borehole in Xiji Town containing barite powder is 2.65 W/m·K. Under stable working condition, the heat exchange rate per meter in summer is 71.92 W/m, and that of extended meters in winter is 44.95 W/m. The heat exchange rate per meter is increased by 2.36 W/m in summer, and the percentage of increase is 3.39%. In winter conditions, the exchange rate per meter is improved by 2.49 W/m, and the improvement ratio is 5.86%. The comparison of winter and summer working conditions shows that the improvement ratio of heat exchange rate is basically equal, but from the improvement ratio, the winter working condition is slightly higher than the summer working condition.

The average thermal conductivity of cement mortar backfilled borehole K3 in Nancha Town, Pinggu District, Mountain Region is 2.59 W/m·K and the measured value of heat transfer rate per meter in summer is 71.15 W/m and 39.34 W/m in winter under stable working condition; the average value of thermal conductivity of cement mortar backfilled borehole K4 in Nancha Town with barite powder is 2.97 W/m·K. The measured value of heat transfer rate per meter in summer is 73.89 W/m and 40.15 W/m in winter under stable working condition. The measured value of heat exchange rate per meter in summer is 73.89 W/m, and the measured value of heat exchange rate per meter in winter is 40.15 W/m. The heat exchange rate per meter in summer is increased by 2.74 W/m, and the improvement ratio is 3.85%. In winter working condition, the heat exchange rate efficiency is improved by 0.81 W/m, and the improvement ratio is 2.06%. Comparing the winter and summer working conditions, the heat exchange and the improvement ratio of the extended meter are slightly higher in the summer working condition than in the winter working condition.

Table 2: List of field thermal response test results

Drill hole number	Initial temperature (℃)	Average thermal conductivity (W/m·K)	Heat exchange power (W/m)		Testing site
			Summer conditions	Winter conditions	
A5 (Medium sand backfill)	16.8	2.17	69.56	42.46	Plain : Xiji Town, Tongzhou District
A7 (Medium sand backfill containing barite powder)	16.7	2.65	71.92	44.95	
K3 (Cement mortar backfill)	14.6	2.59	71.15	39.34	Mountainous area: NanCha Village, Pinggu District
K4 (Cement mortar backfill containing barite powder)	14.2	2.97	73.89	40.15	

4. NUMERICAL SIMULATION OF THE BOREHOLE HEAT TRANSFER CAPACITY

Establish numerical models of buried pipe boreholes in plain areas and mountainous areas, calibrate them with measured data, and then carry out simulation prediction of heat transfer capacity of backfill boreholes

4.1 Model Construction

Both the rock and soil layers within the strata are porous media for heat transfer, whose mathematical equations are

$$(\rho C_P)_{eff}\frac{\partial T}{\partial t} + \rho C_P \mathbf{u}\cdot\nabla T + \nabla\cdot q = Q \quad (1)$$

$$q = -k_{eff}\nabla T \quad (2)$$

Groundwater flow is mathematically modeled using Darcy's Law.

$$\frac{\partial}{\partial t}(\varepsilon_p\rho) + \nabla(\rho v) = Q_m \quad (3)$$

$$v = -\frac{k}{\mu}\nabla \quad (4)$$

Buried pipe heat transfer and water flow can be used non-isothermal pipe flow heat transfer mathematical model.

$$\rho A C_p\frac{\partial T}{\partial t} + \rho A C_p u e_t\cdot\nabla_t T = \nabla_t\cdot(Ak\nabla_t T) + \frac{1}{2}f_D\frac{\rho A}{d_h}|u|u^2 + Q + Q_{wall} \quad (5)$$

where the second part of the right side of the equation represents the frictional heat due to viscous dissipation.

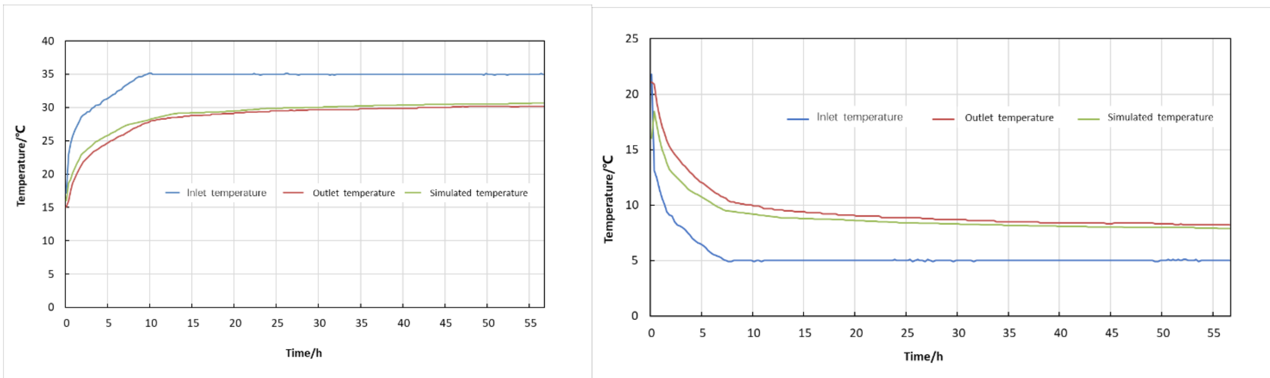
where ρ is the fluid density, kg/m^3; C_P is the constant pressure heat capacity, J/(kg·K); q is the heat flux, W/m^2 ; $\boldsymbol{u}$ is the groundwater flow rate, m/s; k_{eff} is the effective thermal conductivity, W/(m·K); $k_{eff}=(1-\varphi)k_s+\varphi k_l$, k_s and k_l are the thermal conductivity of solid and liquid, respectively, and φ is the porosity, %; Q is the heat source (heat sink), W/m^3; ε_p is the porosity; k is the permeability of porous media, m^2; P is the pressure, pa; Q_m is the mass source term; v is the Darcy flow velocity, m/s; μ is the dynamic viscosity, pa·s; A is the cross-sectional area of the pipe, m^2; C_P is the constant pressure heat capacity, J/(kg·K); μ is the tangential velocity of the circulating fluid, m/s. f_D is the viscosity coefficient; d_h is the average hydraulic diameter, m; Q_{wall} is the heat exchange rate per meter at the pipe wall, W/m.

According to the stratigraphic differences revealed by the boreholes in the study area of Tongzhou plain area in Beijing, the lithology around the boreholes was divided into clay, fine powder sand, medium and coarse sand, and powder soil interlayers according to the lithology. The lithology of the strata in the mountain area is clay, pebble gravel, siltstone, mudstone and quartz sandstone. Establishing the stratigraphic structure and geometry model. In the porous medium heat transfer physical field, the model is set up with linear temperature boundaries around and at the bottom according to the initial geothermal area and geothermal gradient. In Darcy's law physical field, the boundary of the aquifer with a groundwater layer passing through is set as a constant head boundary based on the initial hydraulic gradient, and the boundary of the top and bottom surfaces and the boundary without water flowing through is set as a water barrier. In the turbulent physical field, the initial water pressure in the wellbore is considered according to the hydrostatic pressure, and the wellhead is set as the constant flow boundary after starting the operation. The initial temperature inside the wellbore is equal to the initial temperature of the surrounding geotechnical body, and the temperature is set as the temperature of the fluid at the entrance of the buried pipe after the start of operation. The top of the model is the open boundary. Considering the balance between computational accuracy and computational efficiency, the buried pipe and borehole areas are locally refined when the model is divided into meshes, and the stratification is automatically encrypted.

4.2 Model Validation

The simulation data was fitted to the experimental data in the plain area with the A7 drilling well as an example, and the established double-U buried pipe model was verified in two working conditions, winter and summer. The duration of operation was set to 56 hours, and the inlet temperature of the buried pipe was calculated by using the real time inlet temperature during the test, and then comparing the difference between the test outlet and the model outlet temperature.

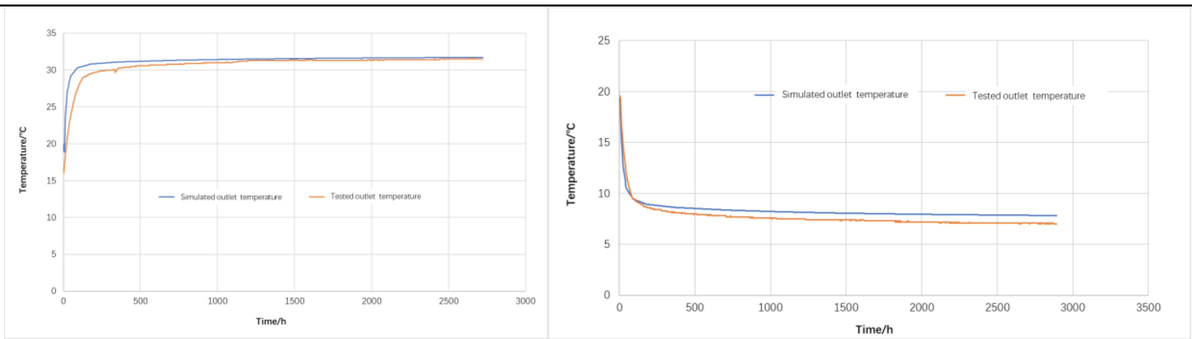
In winter conditions, the inlet temperature decreases rapidly and stabilizes as the operating time increases, during which the simulated outlet temperature fits well with the measured outlet temperature and is overall lower than the measured outlet temperature. At the end of the 56 hours thermal response test, the difference between the simulated and measured outlet temperatures under winter conditions was 0.08°C, with an error of 1.0%. In summer, the inlet temperature increased rapidly and stabilized with the increase of operation time, and the difference between the simulated and measured outlet temperature in summer was 0.70°C with an error of 2.3% after 56 hours of thermal response test.



A:Summer B: Winter

Figure 7: Fit validation graph of borehole outlet temperature in plain

The heat transfer experiment of the hole K4 in the research area of Pinggu District mountain area under stable conditions in summer is conducted. The inlet temperature is set at 35°C. With the extension of heat transfer time, the outlet temperature keeps rising and gradually tends to be stable. When the temperature is stable, there is a difference of 0.2°C between the simulated and measured temperature. Simulate the K4 winter heat transfer experiment, and set the inlet temperature as 5°C. With the extension of heat transfer time, the outlet temperature keeps decreasing and gradually tends to be stable. When the temperature is stable, the outlet temperature difference is 0.8°C (Figure 8).



A:Summer B: Winter

Figure 8: Fit validation graph of borehole outlet temperature in mountain

From the above results, it can be seen that the experimental and simulated data under winter and summer conditions are in good agreement, and the winter condition is the best. The correlation coefficients between the simulated outlet temperature and the experimental outlet temperature in both cases reach above 0.99, which indicates that the chosen research method and the proposed model are relatively reasonable.

4.3 Model Predictions

By raising the content of barite powder to 10%, the heat transfer rate per meter of the plain area in summer is 73.74 W/m, which is 4.18 W/m higher than that of the original backfill of medium sand, with an improved ratio of 6.01%. The heat transfer capacity per meter of the plain area in winter is 46.98 W/m, which is 4.18 W/m higher than that of the medium sand backfill, and the improvement ratio is 10.65%

The heat transfer rate per meter of 75.97 W/m in the summer months in the mountainous area is 4.82 W/m higher than that of the original return fill in the medium sand, representing an increase of 6.77%. The heat transfer rate efficiency of 41.14 W/m in winter in the mountainous area is 1.80 W/m higher than that of the medium sand raw backfill, representing an increase of 4.58%.

Table 3: Numerical simulation results

Model building counterpart sites	Setting inlet water temperature		outlet water temperature		Heat exchange per unit length	
	Cooling season	heating season	Cooling season	heating season	Cooling season	heating season
Plain area	35.00	5.00	32.06	7.68	73.74	46.98
Mountain area			31.97	7.35	75.97	41.14

5. DISCUSSION ON APPLICABILITY OF BACKFILL CONTAINING BARITE

5.1 Enhancement of the Heat Transfer Capacity of Boreholes by Barite Powder

Regardless of plain areas or mountainous areas, the barite powder content in the backfill increases and the heat transfer capacity of buried pipes is improved to different degrees.

For every 5% increase in barite powder content in boreholes in plain areas, the heat transfer capacity increases by 3% in summer and 5% in winter on average; the percentage of heat transfer rate per meter increase in winter in plain areas is slightly higher than that in summer. A 5% increase in barite powder content in boreholes of rocky strata in mountainous areas increases the heat transfer capacity by 3% in summer and 2% in winter. The improvement ratio is about the same in winter and summer in mountainous areas, and slightly higher in summer.

This also highlights a more obvious difference in the heat transfer capacity of the soil layer in the plain area and the rock stratum in the mountainous area. From the lithology of the strata, the strata in the plain area are mainly clay, powder-fine sand, and medium sand, and the average thermal conductivity of the backfilled strata of medium sand raw material is 2.17 W/(m·K) obtained from the stratigraphic thermal response test. The lithology of the mountainous strata is mainly rocky strata with mudstone and siltstone, and the lithology of strata shallower than 15 m is soil and gravel, and the stratigraphic thermal response test obtained an average thermal conductivity of 2.59 W/(m·K) for the medium sand raw material backfill strata. Overall, the thermal conductivity of the mountain strata is higher than that of the plain area.

From the initial temperature, the initial temperature of the stratum in the study area of the plain area within 120 m depth increases with depth below the 20 m thermostatic layer, and the ground temperature is between 14.5 and 16.4°C, with an average stratum temperature of about 15.5°C. The initial temperature of the stratum in the mountainous area ranged from 14.0°C to 14.5°C, and the average temperature of the stratum was about 14.3°C.

After injecting higher temperature water in summer, the lower temperature and larger thermal conductivity of the ground is easier to cool down the high temperature water in the buried pipe, and the heat transfer power is greater, so the heat transfer efficiency of the buried pipe in the mountainous area is higher than that in the plain area in summer. In winter, it is the opposite, because the higher initial ground temperature is easier to obtain heat, and the heat transfer power in winter in the plain area is higher than that in the mountainous area. Therefore, the initial temperature of the ground layer has a greater influence on the heat transfer capacity of buried pipes than the thermal conductivity of the ground layer (Xiaoqing and Yang, 2016).

Looking at the plain area in summer and winter alone, the initial temperature remains unchanged, and the thermal conductivity of the borehole is improved to different degrees by adding barite powder. The enhancement of heat exchange rate in winter and summer in the plain area is basically the same, and the proportion of heat exchange capacity enhancement is slightly higher than that in summer. Therefore, for winter heat extraction, the borehole thermal conductivity is improved, and the heat transfer capacity will be more rapidly improved in winter, and the low temperature water is more sensitive to the change of ground thermal conductivity. In the mountainous area, the initial temperature remains unchanged, and with the addition of barite powder, the thermal conductivity of the stratum increases, and the heat transfer capacity is enhanced more in summer, and the proportion is slightly higher, and the high temperature water is more sensitive to the change of the thermal conductivity of the stratum.

5.2 Flow Stability of Barite Powder

The chemical composition of barite is barium sulfate ($BaSO_4$), barite has a Mohs hardness of 3~3.5, a high specific gravity (4.2~4.7), low hardness and brittle nature, barite is chemically stable, insoluble in water, acids, alkalis and organic intermediates, non-magnetic and non-toxic. Barite powder is inert, easy to disperse, low cohesion, good thermal conductivity, thermal stability and rheological properties, high filler, and has been widely used in oil drilling fluids (Shanshan, 2013; Technical Specification for Drilling Fluids of China National Petroleum Corporation,2010). Due to the strong rheological properties of barite powder, barite powder backfill is suitable in areas with weak groundwater flow.

In general, there is groundwater runoff in the plains and mountainous fracture development areas, and the groundwater flow is closely related to the correlation of the filtering loss of barite powder in the backfill. If the filtering loss of barite powder is high, the thermal conductivity of the backfill will be reduced in the long run. The degree of application and research of barite powder in oil drilling fluids is deep. By reviewing the relevant materials, it is known that in drilling operations, in order to ensure safe drilling, protect the stability of the good wall and inhibit the intrusion of formation fluids, weighted drilling fluids containing barite powder are often configured. Barite in drilling fluid shows more hydrophilic to the liquid phase and better suspension, so the filtering loss of barite powder is related to its hydrophilicity (Yidang et al., 2019). The settling stability of drilling fluid is influenced by the density and granularity of barite (Qiang et al., 2020). When the groundwater is more fluid or the filling method is not appropriate, the effect of heat transfer capacity enhancement will be reduced in the long term. Therefore, the backfill with barite powder is more suitable for mountainous borehole backfill application.

6. CONCLUSION

From the laboratory test results, the heat transfer capacity of the backfill was improved after adding barite powder. The initial thermal conductivity of different medium sand backfill is different, and the thermal conductivity system is improved slightly after adding barite powder. Overall, the percentage of thermal conductivity improvement is about 14% when the specific gravity of barite powder is 5%, and the thermal conductivity improvement is about twice as much as that at 5% specific gravity when the specific gravity of barite powder is within 10%. At 10% to 50%, the thermal conductivity increases slowly. The percentage increase of thermal conductivity is 7.3% when 5% specific gravity of barite powder is added to cement mortar. Compared with medium sand, the enhancement ratio after adding barite powder in cement mortar is lower than that of medium sand backfill.

From the perspective of the actual heat transfer capacity in the plain area, the formation heat transfer rate is improved after 5% increase of barite powder in the backpacking, and the heat transfer rate per meter is increased by 3% in summer and 5% in winter. The ratio in winter is slightly higher than that in summer. For the mountainous area, the heat transfer capacity of the stratum increases after adding barite powder. Heat transfer rate per meter was increased by 3% in summer and 2% in winter, with the ratio slightly higher in summer than in winter.

Calculated by raising the barite powder content to 10%, the heat transfer enhancement ratio per meter in the plain area is 6.0% in summer and 10.6% in winter, as calculated by the model. The heat transfer improvement ratio per meter in mountainous areas is 6.7% in summer and 4.58% in winter. This is in general agreement with the law obtained from the calculation of 5% barite powder content.

The thermal conductivity of the stratum, the initial temperature of the stratum, the thermal conductivity of the stratum after adding barite powder to the backfill in the borehole and the heat transfer capacity of the buried pipe in the borehole are combined in the mountainous and plain areas. Mountain areas have stronger lifting ability in summer, and plain areas are more likely to lift their barite powder content. However, considering the filtering loss of barite powder in the borehole, barite powder is more suitable for application in cement mortar solidification backfill material in mountainous areas.

REFERENCES

Wan WANG: Sustainable design approach of ground resource heat pump, *Journal of Guizhou university (natural sciences)*, 37(2), (2020), 57-60+85.

Yang ZHANG: Optimization and analysis of heat transfer performance of ground source heat pump in Suzhou area, Anhui Jianzhu University, Hefei, China (2021).

Nan WANG， Xiaofeng YANG， Chunlong ZHUANG，Xinyu XI，Boheng FU: Numerical analysis on heat transfer characteristics and thermal effect radius of the u-shaped buried tube. *HV&AC*，45(313)，(2017)：10-14.

Yongying JIA, Zhiwen FANG, Yaxian ZHAO, Xiaoyan LIU: Optimal insulation backfill depth analysis of coaxial deep borehole heat exchanger based on multi-factor orthogonal experiments, *Energy and Buildings*, 273, (2022), 112-114.

Youtang WANG, Bin ZHENG, Chunguang WANG, Chengyu LI, Mingming MAO, Xuyang LIU: Effects of backfill materials on frost heave characteristic of ground heat exchanger, *Transactions of the Chinese Society of Agricultural Engineering*，35(14), (2019), 205-211.

Xianyue SHANG, Yasu ZHOU, Yichao FEI, Huaiyu NIE: Effect of forming temperature and water evaporation on thermal property parameters of buried pipe grouting material. *Journal of donghua university (natural science)*, 45(6), (2019), 951-957.

GB 50336/2009, Technical code for ground-source heat pump system. Ministry of Housing and Urban-Rural Development of the People's Republic of China, General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, (2009).

Ziyuan CHEN, Zhenkai HAO,Xiaofei JI, Ke ZHU: Study on comprehensive performance and energy saving effect of cement based grouting materials for GSHP systems, *Renewable Energy Resources*, 41(4), (2022), 27-30.

Weicui CHEN, Qiaoling LIU, Liqun JIA, Liangliang SUN, Zhaohong FANG: Experimental research on high-performance backfill material s for ground heat exchangers, *HV&AC* , 36(9), 2006, 1-6+23.

Charles P.R: Borehole thermal resistance: Laboratory and field studies, *ASHRAE transactions*, 105(1), (1999),439-445.

Chulho LEE, Kangia LEE, Hangseok CHOI, Hyo-Pum CHOI: Characteristics of thermally-enhanced bentonite grouts for geothermal heat exchanger in South Korea, *Science in China Series E: Technological Sciences,* 53(1), 2010, 123-128.

Xu ZHANG, Xiaobing GAO: Experimental study on thermal conductivity of soil and its mixture with sand, *HV＆AC*, 2004,34(5):216-220.

Ningbo LI, Aihua LIU, Jinping ZHANG, Xiang LI, Jingran DU, Fu LI: Experimental study of barite powder for improving thermal conductivity as bachfill materials of ground heat exchanger, *Journal of Hebei University of Technology,* 47(5), (2018),89-93.

Zilong JIA, Jia ZHENG, Yanchun GUO, Juan LI, Aihua LIU, Bing LIU: Influence of backfilling materials on the heat transfer capacity of buried hole under the lithostra ligraphic condition. *Urban Geology*, 15(04), 2020, 410-414.

ISO 22007-2-2008, Plastics-determination of thermal conductivity and thermal diffusivity-part 2: Transient plane heat source(Hot Disk)method,(2015).

Xiaoqing WANG, Yang WANG: Analysis on the design parameter and performance of vertical ground heat exchanger in soft clay area, *Renewable energy resource*, 2016. 34(11): 1696-1705.

Shanshan WANG: Control analysis of barite powder fineness for drilling fluid, *China Petroleum and Chemical Standard and Quality,* 7, (2013), 84.

Technical Specification for Drilling Fluids of China National Petroleum Corporation, China National Petroleum Corporation, (2010).

Yidang PAN, Peizhi YU, Jingyuan MA: Review on settlement problem of drilling fluid weighting materials, *Drilling Fluid & Completion Fluid*，36(1), (2019),1-9.

Qiang SUN, Zhengsong QIU, Zili LI, Di WANG, Binbin HAO, Hailong MIAO , Tie GENG: Simulation study on sedimentation stability of high density drilling fluid, *Energy Chemical Industry* , 41(6),2020, 49-55.